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**ACOUSTICS DIVISION
RECENT ACCOMPLISHMENTS
AND
RESEARCH PLANS**

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FOR REFERENCE

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ACOUSTICS DIVISION RECENT ACCOMPLISHMENTS AND RESEARCH PLANS

SUMMARY

The research program currently being implemented by the Acoustics Division of NASA Langley Research Center is described. The scope, focus, and thrusts of the research are discussed and illustrated for each technical area by examples of recent technical accomplishments. Included is a list of publications for the last two calendar years. The organization, staff, and facilities are also briefly described.

INTRODUCTION

Acoustics research has been an integral part of the NACA/NASA Langley Research Center program for many years. The discipline has been applied to those aerospace problems believed to be most important at a particular point in time. The problems have included aircraft noise in airport communities, sonic booms, noise inside aircraft cabins, and acoustic loads and sonic fatigue of aircraft structures. The perspective of the research was generally that of classical acoustics . . . i.e., first understanding and reducing the noise; second, understanding and blocking transmission paths of noise; and third, predicting and controlling the impact of noise on receivers, whether they be people or structures. The principal subset of acoustic disciplines involved have been aeroacoustics for research on generation and propagation of noise and acoustic loads by aerodynamic flows, structural acoustics for research on the interaction of sound with aircraft structures, and psychoacoustics for quantifying the impact of aircraft noise on people.

During the post World War II era, the focus of acoustics was on propellers and jet exhausts as the principal sound sources in the propulsion systems of the day. In the 1960's, turbomachinery noise control became a research driver due to the advent of the turbofan engine. Simultaneously, the development of supersonic transports led to a great deal of work on the acoustics of sonic boom generation, propagation, and community impact. In the 1970's, acoustics research expanded rapidly to include the full range of prediction and noise control problems of subsonic commercial transports after the imposition of noise certification requirements by the federal government. As a partial result of this impetus, major progress in community noise control technology for turbofan-powered subsonic transports has occurred, and the technology is being applied to all new generation commercial aircraft entering airline service in the 80's. Consequently, the drivers for acoustics research have changed once more, and the research focus is again shifting.

For the past several months, acoustics research at Langley has undergone an extensive internal assessment by its management and senior research staff. This assessment has involved study groups, management reviews, workshops, consultations with Langley peers in other disciplines, industry visits, and discussions with the professional acoustics research community. From this process has emerged a consensus on the continuing need for discipline-oriented acoustics research and the vehicles and missions that should be the focus for the research. The research in progress has been changing accordingly, but in an evolutionary rather than in a revolutionary way. The program changes may be characterized in a number of ways. One way is as a shift of emphasis from aircraft noise in airport communities to acoustic loads and noise impact on the aircraft. Another way is as a shift of focus from subsonic commercial jet aircraft to propeller and rotor powered aircraft. Still another way is a shift of emphasis from far-field to near-field acoustics.

The purpose of this paper is to describe the present Langley research program that is conceptually illustrated in figure 1. The scope, focus, and directions of the research will be discussed and illustrated with examples of recent contributions.

ACOUSTICS RESEARCH PROGRAM

The mission of the Acoustics Division is to maintain a center-of-excellence for acoustics research at Langley Research Center and to apply the physical science of acoustics and related disciplines to the development of advanced technology for meeting the highest priority national aerospace needs. The current technical goals of the program are:

1. To advance acoustics technology and maintain expertise by conducting pioneering acoustics research to meet high priority needs of the aerospace community.
2. To develop and apply acoustics technology to improve the utility, acceptability, and survivability of civil and military rotorcraft.
3. To develop and apply acoustics technology to remove barriers of passenger and community noise impact on the application of advanced propeller propulsion systems.
4. To develop acoustic technology and research capability for solving critical problems of aerospace vehicles designed to operate in or transition through the hypersonic flight regime.
5. To support the space station program by developing acoustics technology to control the crew environment, improve habitability, and increase productivity.

The research program is structured along discipline lines by technical and functional areas listed in figure 2. The figure indicates the goals supported by each functional research area and shows that research in a particular area is applicable to several technical goals. For example, research in interior acoustics, in addition to addressing general acoustics technology, is focused on problems of particular concern to rotorcraft, advanced propeller aircraft, and space stations.

The research programs, when described in terms of either technical goals or discipline areas, directly support one or more of the following national goals for aeronautics enunciated by the Aeronautical Policy Review Committee of the Office of Science and Technology Policy in reference 1:

1. Subsonics Goal: To Build Trans-Century Renewal
2. Supersonics Goal: To Attain Long Distance Efficiency
3. Transatmospherics Goal: To Secure Future Options

In a similar manner, the research can be related to other goal sets. For example, it is supportive of the NASA aeronautics strategic thrusts to develop technology for subsonic transports, rotorcraft, supersonic cruise aircraft, fighter-attack aircraft, and hypersonic and trans-atmospheric vehicles. It is contained within, and primarily funded by, the NASA Aeronautics Program described in reference 2 for fiscal year 1986.

The level of effort devoted to a particular discipline area or technical goal is determined by technical need, priority, funding availability, staff expertise, and facility capability. In addition to inhouse research, a significant portion of the program is conducted by university grants and industry contracts. The mix changes from year to year depending on programmatic need and availability of funding, expertise, and facilities.

ORGANIZATION AND STAFF

The organization of the Acoustics Division is shown in figure 3 along with key management personnel. The research program is conducted by three branches which are responsible for the functional areas as indicated. The Aeroacoustics Branch and Applied Acoustics Branch conduct aeroacoustic research while structural acoustics research is done by the branch of that name.

The staff consists of about 45 NASA civil service engineers and scientists plus three colocated engineers from the Army Aerostructures Directorate. The staff is roughly evenly distributed in the three branches. Over eighty percent of the staff have a graduate degree and over 25 percent have doctorates. In addition, about 25 non-personnel service contractor engineers and computer scientists work either at or adjacent to Langley Research Center to support and add major capability to the inhouse program. A few other associates participate in resident research through university grants or fellowship programs. The number of such people fluctuates, tending to peak in the summer.

FACILITIES

The Acoustics Division utilizes several facilities to conduct research studies in the areas of aeroacoustics, structural acoustics, and applied acoustics (see refs. 3 and 4). These facilities (see fig. 4 for representative photos) are characterized by special features to minimize unwanted noise due to air handling machinery, valves, etc., and to provide suitable environments for aeroacoustic measurements.

Aircraft Noise Reduction Laboratory

The Aircraft Noise Reduction Laboratory provides the primary focus for the Division's research activities. It consists of the quiet flow facility, the reverberation chamber, the transmission loss apparatus, the human response to noise laboratories, and the space station/aircraft acoustic simulator.

Quiet flow facility - This facility consists of a sound absorbing room in which quiet airflows are available for aeroacoustic testing of model components such as rotors, propellers, inlets, discharge ducts, wings, flaps, struts, cavities, and streamlined bodies. The facility is arranged so that the effects on radiated noise of the interactions of airflows with solid bodies and surfaces can be studied. Special provisions are made for noise control in the low pressure, high pressure, and model air supply systems. The test flow can be varied in Mach number up to 0.5 in the horizontal high pressure leg or Mach number 0.1 in the vertical low pressure leg of the facility.

Reverberation room - The reverberation room can be used as an independent facility or as an integral part of the laboratory's high pressure air system. Model subsonic jet nozzles and suppression devices from 5 to 30 cm (2 to 12 in.) in diameter can be operated in a reverberant environment. The reverberation chamber is used to diffuse the sound generated by a noise source and provides a means of measuring the total acoustic power spectrum of the source.

Transmission loss apparatus - The transmission loss apparatus is a two-room acoustic test facility designed for noise reduction, insertion loss, and transmission loss measurements on aircraft panels. It consists of two chambers, a source room, and a receiving room with an adjoining wall. The source room is used to create an incident sound field on the aircraft panel under test. The second chamber, called the receiving room, is used to measure the noise transmitted through the aircraft panel. The aircraft panel itself is positioned in a 1.23 m by 1.53 m (4 ft. by 5 ft.) section in the adjoining wall between the two rooms.

Typical uses of the transmission loss apparatus have been to measure the transmission loss of simple, built-up, and double wall models of aircraft sidewalls and windows and to optimize the noise control treatments applied to these models. The transmission loss apparatus has also been used to develop new diagnostic measurement techniques used in identifying the source or path of the incoming noise in aircraft cabins.

Human response to noise laboratories. - The human response laboratories consist of the exterior effects room and the anechoic listening room. The exterior effects room is a test area in which subjects are exposed to the types of noises that would be experienced outdoors where aircraft speed, altitude, flight direction, and lateral position can influence the character of the observed noise signatures. A group of subjects can be tested together as a panel or jury. While listening or performing a group activity, this panel rates test noises on absolute scales or as paired comparisons.

The test noises are presented through a system of loudspeakers in the ceiling and walls. Six are distributed over the ceiling and an additional four are located in the walls near the corners of the room. By properly phasing the signals to the speakers, the noise signatures can represent an aircraft flying in a particular direction and at a particular altitude and offset distance, either with or without neighborhood background noise superposed.

The anechoic listening room is a test area in which two subjects can be exposed to noises in an essentially echo-free environment while engaging in basic listening tasks. This area is designed to permit precision calibration of acoustical instruments as well as to support human factors research for free field speech interference and for response to impulsive noise sources.

Space station/aircraft acoustic simulator. - The space station/aircraft acoustic simulator (SS/AAS) is presently nearing operational status. It will be used in the development of interior noise criteria for passenger/crew annoyance, speech intelligibility, and task/activity interruption. The SS/AAS is a floored-cylinder configuration with a diameter of approximately 3.66 m (12.0 ft.) and length of 7.16 m (23.5 ft.). It is designed to accommodate interchangeable interior configurations ranging from candidate space station concepts to actual commercial aircraft interiors. Twenty-four speakers are mounted on the exterior surface of the simulator for use in generating a wide range of aircraft and spacecraft interior noise environments. Additional speakers can be located within the simulator to represent specific interior noise sources. When used in an aircraft configuration, the SS/AAS can contain up to 24 seated subjects. The SS/AAS is expected to provide a versatile test bed for the evaluation of noise-related human factors problems as well as a means for direct assessment of advanced noise control methods.

Jet Noise Laboratory

The main components of the Langley Jet Noise Laboratory are an air system capable of supplying the required flow for supersonic nozzles up to 5 cm (2 in.) in diameter in each of two airstreams [6-cm (2.5-in.) diameter for single nozzle operation with interior plug], dual electric heater units, a test area, eductor and inductor systems, and a small anechoic calibration chamber. Research activities include basic studies of the relationships between the radiated noise and the large scale flow structures in both subsonic and supersonic jets. Also, the coannular supersonic jets are being used to study turbulence evolution in the two interacting shear flows which are typical of high-speed aircraft engines.

Thermal Acoustic Fatigue Apparatus

The thermal acoustic fatigue apparatus provides capability to subject flat structural panels to high level acoustic pressures and high temperature radiant heating. The sound is generated by two electro-pneumatic sources of 60,000 acoustic watts, and is guided by a concrete duct so as to propagate parallel to the test panel. Radiant heat is generated by quartz lamps or graphite heating elements facing the test panel on the opposite side of the duct at a distance of 0.30 to 0.61 m (1 to 2 ft.). The assembly of duct, noise sources, heating equipment, and test panel is located in a test chamber having sufficient space to accommodate special fixtures that may be required for a particular test. Panel instrumentation is wired to a control room outside the test chamber.

Anechoic Noise Facility

The Anechoic Noise Facility consists of an anechoic room in which jet noise experiments and duct propagation experiments can be conducted. An air supply system for model jet operation is provided. The high pressure air supply is used primarily for simulating aircraft engine exhaust flow. Appropriate control valves, mufflers, and a settling chamber are provided to ensure quiet airflow for jet nozzle experiments. Gases other than air may be used.

ACCOMPLISHMENTS AND PLANS

Aeroacoustics Branch

The primary responsibility of the Aeroacoustics Branch is to provide new technology for source noise analyses and prediction. Research programs in FY 86 include rotorcraft noise, jet plume dynamics and aeroacoustic fatigue loads, theory and computer code development for advanced propeller noise prediction, and the development of computational methods for aeroacoustics. Diversity of skills among the branch staff enables the branch to support aeroacoustic technological development for all three vehicle classes envisioned in the policy statement of "National Aeronautical R&D Goals" issued by the Executive Office of the President: trans-century subsonic aircraft, efficient long-range supersonic transport, and transatmospheric hypersonic vehicle. A montage depicting branch research is shown in figure 5. A five-year program plan providing an outline of research activities within the branch is shown in figure 6.

Recent technical accomplishments of the Aeroacoustics Branch are listed below. They are presented in narrative and graphic form in figures 7 through 9.

Rotorcraft Aeroacoustics (figs. 7(a) - 7(e))

- A New Technique for Removal of Contamination from Airfoil Broadband Noise Spectra

- Scaling of Surface Pressure Spectra for Turbulent Boundary Layers
- Tip Vortex Formation Noise
- Main Rotor In-Flow Turbulence Measurement
- Characterization of Two Dimensional Blade-Vortex Interaction

Computational Aeroacoustics (figs. 8(a) - 8(f))

- The Prediction of Noise of Advanced Propellers Based on a New Acoustic Formulation.
- The Mean Surface Approximation to a Formulation for the Prediction of Supersonic Propeller Noise
- Aerodynamic Computation Using Acoustic Formulation
- Helicopter Discrete Frequency Noise Prediction
- Vortex Distortion During Blade/Vortex Interaction
- Vortex Studies Relating to Boundary Layer Turbulence and Noise

Jet Noise (figs. 9(a) - 9(d))

- Simulated Flight Effects on Supersonic Jet Noise
- Acoustic Loading from Dual Supersonic Jets
- Load Reduction Associated with Twin Supersonic Plume Resonance
- Acoustic Properties of a Non-Axisymmetric Supersonic Nozzle

The FY 86 plans for the Aeroacoustics Branch are given in figure 10 by technical area. A narrative discussion of the plans is given in figure 11.

Applied Acoustics Branch

The Applied Acoustics Branch is involved in both experimental and theoretical research with an emphasis on the experimental. The branch is divided into four principal areas which are: helicopter acoustics, propeller acoustics, boundary layer acoustics, and fundamental studies of atmospheric propagation. With the exception of the NASA/AHS Helicopter Noise Program the majority of the research of this branch is an in-house activity with an associated university grant program.

The program goals of the branch are as follows: to understand, predict, and control the near- and far-field noise of installed propellers; to understand, predict, and control the interaction of acoustic waves and generation of acoustic loads by boundary layer flows; to improve understanding and predictability of long range, low altitude propagation of noise from

aircraft and rotorcraft and to develop, evaluate, and transfer to industry technology to enable rotorcraft to be designed and operated to meet community noise requirements. Various research activities of the Applied Acoustics Branch are highlighted with the assorted pictures given in figure 12. A five-year plan for the branch is given by the flow chart presented in figure 13.

Recent technical accomplishments of the Applied Acoustics Branch are listed below. They are presented in narrative and graphic form in figures 14 through 17.

Boundary Layer Acoustics (figs. 14(a) - 14(e))

- Effects of Noise on Laminar Flow
- Fluctuating Loads on a Laminar-Flow Gloved-Wing Section of a 757 in Flight
- Comparison of Mean Flow Effects on Responses of a Pressure Probe and Hot Film Probe to Acoustic Excitation
- Calculating Admittances of Test Specimens in Ducts with Flow Gradients in Two Cross-Sectional Directions
- Effects of Source Separation and Phasing on Power Developed in a Semi-Reverberant Enclosure with Application to Active Noise Control

Helicopter Acoustics (figs. 15(a) - 14(b))

- NASA/AHS Helicopter Noise Reduction Program
- ROTONET

Atmospheric Propagation (figs. 16(a) - 16(b))

- Evaluation of Scale-Model Experimental setup for Studying Sound Propagation at small Angles of Incidence over Ground Terrain
- Propagation Near an Acoustic Shadow Zone caused by a Lapse Temperature Gradient

Propeller Acoustics (figs. 17(a) - 17(b))

- Directivity Characteristics of Pusher Propeller Noise
- Single- and Counter-Rotation Propeller Noise Comparison

The FY 86 plans for the Applied Acoustics Branch are given in figure 18 by technical area. A narrative discussion of the plans is given in figure 19.

Structural Acoustics Branch

The Structural Acoustics Branch conducts research to understand, predict, and reduce noise inside aircraft, rotorcraft, spacecraft and to understand, predict, and control the response of aerospace vehicles to intense acoustic loads which can lead to sonic fatigue. In addition, the Branch conducts research to develop techniques for active noise control and other advanced noise control methodologies and to quantify the subjective impact of noise on passengers, crew, and communities. The extent of the Branch research activities in these four disciplinary areas is outlined in figure 20. The Branch's research plans are projected for a five-year period in figure 21.

Recent accomplishments of the Structural Acoustics Branch are given in title form below. These are followed by descriptive write-ups in figures 22 through 25.

Interior Acoustics (figs. 22(a) - 22(j))

- Interaction Between Airborne and Structureborne Noise
- Transmission Loss of Finite Composite Panels
- Modal Response and Noise Transmission of Composite Panels
- Comparison of Noise Transmission Prediction for Composite and Aluminum Fuselage Sections
- Structureborne Noise Measurement Technique Development
- Effects of Temperature and Sound Source Angle on Aircraft Cabin Noise
- Noise Transmission Through Aircraft Windows
- Flight Study of Aircraft Sidewall Noise Transmission
- Validation of Propeller Aircraft Interior Noise Model
- Validation of Helicopter Interior Noise Model

Sonic Fatigue and Response (fig. 23)

- Acoustic Response and Fatigue of Advanced Composites

Active Noise Control (figs. 24(a) - 24(d))

- Active Control of Random Noise
- Control of Interior Noise by Propeller Synchrophasing

- Active Vibrational Control of Interior Noise
- Active Interior Noise Control Modeling

Subjective Acoustics (figs. 25(a) - 25(b))

- Quantification of Advanced Turboprop Aircraft Flyover Noise
- Helicopter Community Noise Study

The FY 86 plans for the Structural Acoustics Branch are summarized in figure 26. A detailed discussion of the plans is given in figure 27.

ACOUSTICS PUBLICATIONS

The recent work of the Acoustics Division resulted in considerable output during 1984 and 1985. The extent of the Division's accomplishments is indicated by the list of publications presented below. The publications are given as (a) formal NASA reports, (b) quick-release technical memorandums, (c) contractor reports, (d) journal articles and other publications, (e) meeting presentations, (f) technical talks, (g) computer programs, and (h) tech briefs.

PUBLICATIONS - 1984

Formal Reports

1. Anon.: Helicopter Noise Reduction Program - 1983. NASA CP-2308, May 1984, 328 p.
2. Block, P. J. W.: Analysis of Noise Measured From a Propeller in a Wake. NASA TP-2358, November 1984, 48 p.
3. Block, P. J. W.; and Gentry, G. L., Jr.: Evaluation of the Langley 4- by 7-Meter Tunnel for Propeller Noise Measurements. NASA TM -85721, December 1984, 28 p.
4. Golub, R. A.; and Preisser, J. S.: Test-Engine and Inlet Performance Fan Aircraft Used for Investigating Flight Effects on Fan Noise. NASA TP 2254, TP-2254, April 1984, 68 p.
5. Kryter, K. D.: Physiological, Psychological, and Social Effects of Noise. NASA RP-1115, July 1984, 658 p.
6. Leatherwood, J. D.; and Barker, L. M.: A User-Oriented and Computerized Model for Estimating Vehicle Ride Quality. NASA TP-2299, April 1984, 43 p.

7. Leatherwood, J. D.; Clevenson, S. A.; and Hollenbaugh, D. D.: Evaluation of Ride Quality Prediction Methods for Helicopter Interior Noise and Vibration environments. NASA TP-2261, AVSCOM TR 84-D-2, March 1984, 45 p.
8. McCurdy, D. A.; and Powell, C. A.: Annoyance Caused by Propeller Airplane Flyover Noise. NASA TP-2356, August 1984, 50 p.
9. Mueller, A. W.: Study of Stator-Vane Fluctuating Pressures in a Turbofan Engine for Static and Flight Tests. NASA TP-217, April 1984, 52 p.
10. Norum, T. D.; and Shearin, J. G.: Effects of Simulated Flight on the Structure and Noise of Underexpanded Jets. NASA TP-2308, May 1984, 30 p.
11. Watson, W. R.: A New Method for Determining Acoustic-Liner Admittance in a Rectangular Duct With Grazing Flow From Experimental Data. NASA TP-2310, July 1984, 17 p.
12. Willis, C. M.; and Mayes, W. H.: Noise-Reduction Measurements on Stiffened and Unstiffened Cylindrical Models of an Airplane Fuselage. NASA TM-85716, February 1984, 26 p.

Quick-Release Technical Memorandums

13. Block, P. J. W.: Installation Noise Measurements of Model SR and CR Propellers. NASA TM-85790, May 1984, 102 p.
14. Block, P. J. W.: Noise Generated by a Propeller in a Wake. NASA TM 85794, May 1984, 64 p.
15. Clevenson, S. A.; and Roussos, L. A.: Effect of External Pressure Environment on the Internal Noise Level Due to a Source Inside a Cylindrical Tank. NASA TM-85814, August 1984, 23 p.
16. *Conner, D. A.; and *Hoad, D. R.: Experimental Blade Vortex Interaction Noise Characteristics of a Utility Helicopter at 1/4 Scale. NASA TM-84653, AVSCOM TM-83-B-1, January 1984, 273 p.
17. Leatherwood, J. D.: Combined Effect of Noise and Vibration on Passenger Acceptance. NASA TM-86284, August 1984, 34 p.
18. Mixson, J. S.; O'Neal, R. L.; and Grosveld, F. W.: Investigation of Fuselage Acoustic Treatment for a Twin-Engine Turboprop Aircraft in Flight and Laboratory Tests. NASA TM-85722, January 1984, 36 p.
19. Willshire, K. F.: Aircraft and Background Noise Annoyance Effects. NASA TM-85744, January 1984, 30 p.

*Army Structures Laboratory (AVSCOM)

20. Willshire, K. F.: Human Response to Vibroacoustic Environments of Space Vehicles. NASA TM-86316, October 1984, 36 p.

Contractor Reports

21. Bilanin, A. J.; Hecht, A. M.; and Sandri, G. O.: A Mean Square Formulation of the Aerodynamic Sound Generation Problem. (NAS1-16861 Continuum Dynamics, Inc.) NASA CR-172356, March 1984, 39 p.
22. Dash, S. M.; and Wolf, D. E.: Fully-Coupled Analyzing Jet Mixing Problems, Part I: Shock Capturing Model, SCIPUIS. NASA CR-3761, Jan. 1984.
23. Fuller, C. R.: Analytical Investigation of Synchrophasing as a Means of Reducing Aircraft Interior Noise. (NAG1-390 Virginia Polytechnic Institute and State University.) NASA CR-3823, August 1984, 42 p.
24. George, A. R.; and Chou, S-T.: Broadband Rotor Noise Analyses. (NAG1-107 Cornell University.) NASA CR-3797, April 1984, 98 p.
25. Hayden, R. E.: Comparison of Options for Reduction of Noise in the Test Section of the NASA Langley 4 x 7m Wind Tunnel Including Reduction of Nozzle Area. (NAS1-16521 Bolt Beranek and Newman Inc.) NASA CR 172446-2, September 1984, 51 p.
26. Holm, R. G.: JT15D Simulated Flight Data Evaluation. (NAS1-16776 General Electric Company.) NASA CR-172322, September 1984, 197 p.
27. Howe, M. S.: On the Long Range Propagation of Sound Over Irregular Terrain. (NAS1-16521 Bolt Beranek and Newman Inc.) NASA CR-3862, December 1984, 36 p.
28. Hubbard, H. H.; and Shepherd, K. P.: The Effects of Blade Mounted Vortex Generators on the Noise From a MOD-2 Wind Turbine Generator. (NAG1-166 The College of William and Mary, Virginia Associated Research Campus, and NAS1-16978 The Bionetics Corporation.) NASA CR-172292, February 1984, 22 p.
29. Hubbard, H. H.; and Shepherd, K. P.: Response Measurements for Two Building Structures Excited by Noise From a Large Horizontal Axis Wind Turbine Generator. (NAG1-166 The College of William and Mary, Virginia Associated Research Campos, and NAS1-16978 The Bionetics Corporation.) NASA CR-172482, November 1984, 24 p.
30. Junger, M. C.; Garrellick, J. M.; Martinez, R.; and Cole, J. E., III: Analytical Model of the Structureborne Interior Noise Induced by a Propeller Wake. (NAS1-17570 Cambridge Acoustical Associates, Inc.) NASA CR-172381, May 1984, 97 p.
31. Pope, L. D.: Propeller Aircraft Interior Noise Model - Utilization Study and Validation. (NAS1-17281 L. D. Pope, Consulting Engineer.) NASA CR-172428, September 1984, 246 p.

32. Pope, L. D.; Wilby, E. G.; and Wilby, J. F.: Propeller Aircraft Interior Noise Model. (NAS1-15782 Bolt Beranek and Newman Inc.) NASA CR-3813, July 1984, 166 p.
33. Prydz, R. A.; and Balena, F. J.: Window Acoustic Study for Advanced Turboprop Aircraft. (NAS1-16441 Lockheed-California Company.) NASA CR 172391, August 1984, 48 p.
34. Russell, J. W.: An Empirical Method for Predicting the Mixing Noise Levels of Subsonic Circular and Coaxial Jets. (NAS1-16000 Kentron International, Inc.) NASA CR-3786, February 1984, 123 p.
35. Shepherd, K. P.; and Hubbard, H. H.: Acoustic Tests of the MOD-0/5A Wind Turbine Rotor With Two Different Ailerons. (NAS1-16978 The Bionetics Corporation and NAG1-166 The College of William and Mary, Virginia Associated Research Campus.) NASA CR-172427, August 1984, 30 p.
36. Vaicaitis, R.; Bofilios, D. A.; and Eisler, R.: Experimental Study of Noise Transmission Into a General Aviation Aircraft. (NSG-1450 Columbia University.) NASA CR-172357, June 1984, 153 p.
37. Wilby, E. G.; and Wilby, J. F.: Application of Stiffened Cylinder Analysis to ATP Interior Noise Studies. (NAS1-16521 Bolt Beranek and Newman Inc.) NASA CR-172384, August 1984, 130 p.
38. Zalas, J. M; and Tichy, J.: Active Attenuation of Propeller Blade Passage Noise. (NAS1-17231 Lord Corporation.) NASA CR-172386, July 1984, 85 p.

Journal Articles and Other Publications

39. Brooks, T. F.; and Schlinker, R. H.: Progress in Rotor Broadband Noise Research. Vertica, Volume 7, No. 4, 1983, p. 287-307.
40. Cooper, P. A.; Miserentino, P.; Sawyer, J. W.; and Leatherwood, J. D.: Effect of Simulated Mission Loads on Orbiter Thermal Protection System Undensified Tiles. J. of Spacecraft and Rockets, Vol. 21, No. 5, Sept-Oct. 1984.
41. Farrassat, F.: Comments on "Derivation of the Fundamental Equation of Sound Generated by Moving Aerodynamic Surfaces" by Hans R. Aggarwal. AIAA Journal, Volume 22, No. 8, August 1984, p. 1183-1184.
42. Farrassat, F.: A New Aerodynamic Integral Equation Based on an Acoustic Formula in the Time Domain. AIAA Journal, Volume 22, No. 9, September 1984, p. 1337-1340.
43. Farassat, F.: Solution of the Wave Equation for Open Surfaces Involving a Line Integral Over the Edge. Journal of Spacecraft and Rockets, Volume 95, No. 1, July 8, 1984, p. 136-141.

44. Farassat, F.; and Succi, G. P.: The Prediction of Helicopter Rotor Discrete Frequency Noise. Vertica, volume 7, no. 4, 1983, p. 309-320.
45. Fields, J. M.: The Effect of Numbers of Noise Events on People's Reactions to Noise: An Analysis of Existing Survey Data. The Journal of the Acoustical Society of America, Volume 75, No. 2, February 1984, pp. 447-467.
46. Fuller, C. R.: Propagation and Radiation of Sound from Flanged Circular Ducts with Circumferentially Varying Wall Admittances-I. Semi-Infinite Ducts. Journal of Sound and Vibration, Volume 93, April 8, 1984, pp. 341-351.
47. Fuller, C. R.: Propagation and Radiation of Sound from Flanged Circular Ducts with Circumferentially Varying Wall Admittances-II. Finite Ducts with Sources. Journal of Sound and Vibration, Volume 93, No. 3, April 1984, pp. 781-785.
48. Fuller, C. R.; and Silcox, R. J.: Experiments on Sound Radiation from a Duct with a Circumferentially Varying Liner. AIAA Journal, Volume 22, June 1984, p. 781-785.
49. Fuller, C. R.: Monopole Excitation of Vibration in an Infinite Cylindrical Elastic Shell Filled with Fluid. J. Sound and Vibration, Vol. 96 (Pt. 1) 1984, pp. 101-110.
50. Fuller, C. R.: The Input Mobility of an Infinite Circular Cylindrical Elastic Shell Filled with Fluid. J. Sound and Vibration, Vol. 87, (Pt. 3) 1983, pp. 409-427.
51. Fuller, C. R.: Sound Transmission Through Cylindrical Sheels. Inter-Noise, Vol. 1, Dec. 1984, pp. 269-272.
52. Hardin, J. C.; and Lamkin, S. L.: Aeroacoustic Computation of Cylinder Wake Flow. AIAA Journal, Volume 22, No. 1, January 1984, pp. 51-57.
53. Hardin, J. C.; and Mason, J. P.: Periodic Motion of Two and Four Vortices in a Cylindrical Pipe. The Physics of Fluids, Volume 27, No. 7, July 1984, p. 1583-1589.
54. Hariharan, S. I.; and Lester, H. C.: A Finite Difference Solution for the Propagation of Sound in Near Sonic Flows. The Journal of the Acoustical Society of America, Volume 75, No. 4, April 1984, p. 1052-1061.
55. Leatherwood, J. D.; Clevenson, S. A.; and Hollenbaugh, D. D.: Evaluation of Ride Quality Prediction Methods for Operational Military Helicopters. Journal of the American Helicopter Society, Volume 29, July 1984, pp. 11-17.
56. Lester H. C.; Preisser, J. S.; and Parrott, T. L.: The Design and Flight Test of a Kevlar Acoustic Liner. Journal of Aircraft, Volume 21, No. 7, July 1984, pp. 491-497.

57. Preisser, J. S.; and Chestnutt, D.: Flight Effects on Fan Noise with Static and Wind Tunnel Comparisons. Journal of Aircraft, Volume 21, July 1984, pp. 453-461.
58. Raney, J. P.; and *Hoad, D. R.: Creating Competitive Rotorcraft Noise Technology. Aerospace America, Volume 22, February 1984, pp. 60-63.
59. Roussos, L. A.; Powell, C. A.; Grosveld, F. W.; Koval, L. R.: Noise Transmission Characteristics of Advanced Composite Structural Materials. Journal of Aircraft, Volume 21, July 1984, pp. 528-535.
60. Seiner, J. M.; and Yu, J. C.: Acoustic Near-field Properties Associated with Broad Band Shock Noise. AIAA Journal, volume 22, no. 9, September 1984, pp. 207-1215.
61. Silcox, R. J.: Geometry and Static Flow Effects on Acoustic Radiation from Ducts. AIAA Journal, Volume 22, No. 8, August 1984, pp. 1087-1093.
62. Van Morhem, W. K. and Landheim, Gregory K.: The Propagation of Plane Waves in a Thermally Stratified Atmosphere. JASA, Vol 76. No. 3, Sept. 1984, pp. 867.
63. Watson, W. R.: An Acoustic Evaluation of Circumferentially Segmented Duct Liners. AIAA Journal, Volume 22, No. 9, September 1984, p. 1229-1233.

Meeting Presentations

64. Beyer, T. B.; Powell, C. A.; Daniels, E. F.; and Pope, L. D.: Effects of Acoustic Treatment on the Interior Noise Levels of a Twin-Engine Propeller Aircraft--Experimental Flight results and Theoretical Predictions. Presented at the AIAA/ANSA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84-2331.
65. Block, P. J. W.: The Effects of Installation on Single- and Counter-Rotation Propeller Noise. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84-2263.
66. Booth, E. R., Jr.; and Yu, J. C.: Two Dimensional Blade-Vortex Interaction Flow Visualization Investigation. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84-2307.
67. Brooks, T. F.; and Marcolini, M. A.: Airfoil Tip Vortex Formation Noise Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84-2308.

*Army Structures Laboratory (AVSCOM)

68. Brooks, T. F.; Marcolini, M. A.; and Pope, D. S.: Airfoil Trailing Edge Flow Measurements and Comparison with Theory Incorporating Open Wind Tunnel Corrections. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84-2266.
69. Eversman, W.; Parrott, A. V.; Preisser, J. S.; and Silcox, R. J.: Contributions to the Finite Element Solution of the Fan Noise Radiation Problem. Presented at the 1984 ASME Winter Annual Meeting, December 9-14, 1984, New Orleans, Louisiana.
70. Farassat, F.: The Unified Acoustic and Aerodynamic Prediction Theory of Advanced Propellers in the Time Domain. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84-2303.
71. Farassat, F.: Theoretical Analysis of Linearized Acoustics and Aerodynamics of Advanced Supersonic Propellers. Presented at the AGARD Fluid Dynamics Panel Symposium on Aerodynamics and Acoustics of Propellers, October 1-4, 1984, Toronto, Canada.
72. Fuller, C. R.: Noise Control Characteristics of Synchrophasing- An Analytical Investigation. Presented at the AIAA/NASA 9th Aeroacoustics Conference, Williamsburg, VA, Oct. 15-17, 1984, AIAA-84-2369.
73. Fuller, C. R. and Jones, J. D.: Noise Control Characteristics of Synchro-phasing--An Experimental Investigation. Presented at the AIAA/NASA 9th Aeroacoustics Conference, Williamsburg, VA, Oct. 15-17, 1984, AIAA-84-2370.
74. Grandle, R. E.: Aircraft Noise Synthesis System: Computer Algorithms and Methods. Presented at the 107th Meeting of the Acoustical Society of America, May 7-10, 1984, Norfolk, Virginia. Published in the Journal of the Acoustical Society of America, Supplement 1, Volume 75, Spring 1984, p.80.
75. Grosveld, F. W.; and Mixson, J. S.: Noise Transmission Through an Acoustically Treated and Structurally Stiffened Aircraft Sidewall. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg Virginia. AIAA Paper No. 84-2329.
76. Hardin, J. C.; and Lamkin, S. L. Aeroacoustic Interaction of a Distributed Vortex With a Lifting Joukowski Airfoil. Presented at the AIAA/NASA 9th AIAA Paper No. 84-2287.
77. Hardin, J. C.; and Mason, J. P.: A New Look at Sound Generation by Blade/Vortex Interaction. Presented at the 1984 ASME Winter Annual Meeting, December 9-14, 1984, New Orleans, Louisiana. Paper No. 84-041.
78. *Heitman, K. E.; and Mixson, J. S.; Laboratory Tests on an Aircraft Fuselage to Determine the Insertion Loss of Various Aoustic Add-On Treatments. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84-2330.

*Army Structures Laboratory (AVSCOM)

79. Leatherwood, J. D.: Passenger Discomfort Response to Combined Noise and Vibration. Presented at the 108th Meeting of the Acoustical Society of America, October 9-12, 1984, Minneapolis, Minnesota. Abstract published in Journal of the Acoustical Society of America, Supplement 1, Volume 76, Fall 1984, p. 56.
80. Martin, R. M.: Comparison of Noise Prediction for the X-Wing System and a Conventional Rotor in Hover. Presented at the AHS 40th Annual Forum and Technical Display, May 16-18, 1984, Crystal City, Virginia. AHS Paper No. A-84-40-03-D000. In Proceedings, p. 9-17.
81. Martin, R. M.; *Elliott, J. W.; and *Hoad, D. R.: Comparison of Experimental and Analytic Predictions of Rotor Blade-Vortex Interactions Using Model Scale Acoustic Data. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84, 2269.
82. McAninch, G. L.: Higher-Order Parabolic Approximations for Sound Propagation in Stratified Moving Media. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia.
83. McAninch, G. L.; and Rawls, J. W., Jr.: Effects of Boundary Layer Refraction and Fuselage Scattering on Fuselage Surface Noise From Advanced Turboprop Propellers. Presented at the AIAA 22nd Aerospace Sciences Meeting, January 9-12, 1984, Reno, Nevada. AIAA Paper No. 84-0249.
84. McCurdy, D. A.: Aircraft Noise Synthesis System: An Introduction. Presented at the 107th Meeting of the Acoustical Society of America May 7-10, 1984, Norfolk, Virginia. Published in the Journal of the Acoustical Society of America, Supplement 1, Volume 75, Spring 1984, p. 80.
85. McCurdy, D. A.: Quantification of Advanced Turboprop Aircraft Flyover Noise Annoyance. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84-2293.
86. Mixson, J. S.; and Powell, C. A.: Review of Recent Research on Interior Noise of Propeller Aircraft. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia.
87. Norum, T. D.: Control of Jet Shock Associated Noise by a Reflector. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84-2279.
88. Padula, S. L.; and Block, P. J. W.: Acoustic Prediction Methods for the NASA Generalized Advanced Propeller Analysis System (GAPAS). Presented at the AIAA/NASA General Aviation Technology Meeting, July 10-12, 1984, Hampton, Virginia. AIAA Paper No. 84-2243-CP.
89. Padula, S. L.; and Block, P. J. W.: Predicted changes in Advanced Turboprop Noise With Shaft Angle of Attack. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84-2347.

90. Patterson, J. L. Jr.; Seiner, J. M.; Hardin, J. C.; Levasseur, J. E.; Manning, J. C.; Kadirka, P. U.; and York, J. A.: Further Validation of the Vortex Theory of Breath Sound Generation at International Conference on Lung Sounds, Cincinnati, OH, Sept. 20-21, 1984.
91. Seiner, J. M.: Advances in High Speed Jet Aeroacoustics. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84-2275.
92. Smith, C. D.; and Silcox, R. J.: An Experimental Investigation of Active Noise Control in Ducts. Presented at the 107th Meeting of the Acoustical Society of America, May 7-10, 1984, Norfolk, Virginia. Published in the Journal of the Acoustical Society of America, Supplement 1, volume 75, Spring 1984, p. 91.
93. Tam, C. K. W.; Seiner, J. M.; and Yu, J. C.: On the Relationship Between Broadband Shock Associated Noise and Screech Tones. Presented at the AIAA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84-2276.
94. Vaicaitis, R.; Grosveld, F. W.; and Mixson, J. S.: Noise Transmission Through Aircraft Panels. Presented at the AIAA/ASME/ASCE/AHS 25th Structures, Structural Dynamics and Materials Conference, May 14-16, 1984, Palm Springs, California. AIAA Paper no. 84-0911.
95. Vaicaitis, R.; and Mixson, J. S.: Theoretical Design of Acoustic Treatment for Cabin Noise Control of a Light Aircraft. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 4-2328.
96. Willshire, K. F.: Human Response to Vibroacoustic Environments of Space Vehicles. Presented at the 108th Meeting of the Acoustical Society of America, October 9-12, 1984, Minneapolis, Minnesota. Abstract published in Journal of the Acoustical Society of America, Supplements, 1, Volume 76, Fall 1984, p. 553.
97. Willshire, W. L., Jr.; and Martin, R. M.: Noise and Performance Characteristics of a Model Scale X-Wing Rotor System in Hover. Presented at the AIAA 22nd Aerospace Sciences Meeting, January 9-12, 1984, Reno, Nevada. AIAA Paper No. 84-0337.
98. Zaman, K. B. M. Q.: Mechanism of Broadband Jet Noise Amplification and Suppression Under Controlled Excitation. Presented at the AIAA/NASA 9th Aeroacoustics Conference, October 15-17, 1984, Williamsburg, Virginia. AIAA Paper No. 84-2319.
99. Fuller, C. R.: An Analytical Model for Investigation of Interior Noise Characteristics in Aircraft. Presented at the SAE/NASA 2nd Aircraft Interior Noise Meeting, Oct. 18-19, 1984.

100. Fuller, C. R.: An Analytical Investigation of Synchrophasing as a Means of Reduction of Aircraft Interior Noise. Presented at the SAE/NASA 2nd Aircraft Interior Noise Meeting, Oct. 18-19, 1984. NASA 75 (S-1) S-79, 1984.
101. Fuller, C. R.: Point Source Excitation of Cylindrically Elastic Shells Filled with Fluid. Presented at 107th Meeting of the ASA, Norfolk, VA, May 7-10, 1984.
102. Grosveld, F. W.; and Mixson, J. S.: Sound Transmission Through Honeycomb Stiffened Panels. Presented at the 107th Meeting of the Acoustical Society of America, May 7-10, 1984, Norfolk, Virginia.
103. Hardin, J. C.: Vortex Motion in Pipes. Kentron International Seminar Series. Hampton, Virginia, April 11, 1984.
104. Hardin, J. C.; Lamkin, S. L.; and Mason, J. P. Aeroacoustic Computation of Blade/Vortex Interaction. Presented at the U.S. Army Workshop on Aerodynamics and Acoustics of Blade-Vortex Interactions, October 29-31, 1984, Moffett Field, California.
105. Leatherwood, J. D.: Combined Affects of Noise and Vibration on Passenger Acceptance. Presented at the 108th ASA Meeting October 8-12, 1984, Minneapolis, Minnesota.
106. McAninch, G. L.: ANOPP Capability as it Relates to Interior Noise Prediction. Presented at the SAE/NASA 2nd Aircraft Interior Noise Meeting, October 18-19, Hampton, Virginia.
107. McGary, M. C.: Separation of Airborne and Structureborne Noise in Propeller Driven Aircraft. Presented at the SAE/NASA 2nd Aircraft Interior Noise Meeting, October 18-19, 1984, Hampton, Virginia.
108. Pao, S. P.: Aeroacoustic Research at Langley. Penn State Univ. Lecture, March 13, 1984.
109. Roussos, L. A.: Noise Transmission Loss of a Rectangular Plate in an Infinite Baffle. Presented at the 107th Meeting of the Acoustical Society of America, May 7-10, 1984, Norfolk, Virginia.
110. Stephens, D. G.: Acoustics in Space. Presented at 37th Meeting of North Carolina Regional Chapter of the ASA, November 1-2, 1984, Charlotte, North Carolina.
111. Willshire, K. F.: Human Response to Vibroacoustics Environments of Space Vehicles. Presented at the Naval Biodynamics Laboratory Seminar, September 7, 1984, New Orleans, Louisiana.
112. Willshire, K. F.: Noise Environments of Spacecraft - Past, Present, and Future. Presented at the DC Chapter Meeting of the Acoustical Society of America, December 11, 1984, Washington, DC.

113. Yu, J. C.; and Booth, E. R., Jr.: Flow Field Visualization of Two-Dimensional Blade Vortex Encounter. Presented at the U.S. Army Workshop on Aerodynamics and Acoustics of Blade/Vortex Interactions, October 29-31, 1984, Moffett Field, California.

Computer Programs

114. Barker, L. M. (Systems Development Corporation); and Leatherwood, J. D. (Langley Research Center): Simplified NASA Ride Comfort Model Program (RIDEQUL). Program No. LAR-13289.

Tech Briefs

115. Manning, J. C.; and Simpson, J. W.: Miniature Microphone Adapter. NASA Tech Brief LAR-13210.

116. Martin, R. M.; and Brooks, T. F.: Reduction of Vane Noise in Wind-Tunnel Nozzles. NASA Tech Brief LAR-13333.

117. McGary, M. C.; and Mayes, W. H.: Noise Path Separation Device. NASA Tech Brief LAR-13017.

118. Unruh, J. F.; and Scheidt, D. C. (Southwest Research Institute): Predicting Noise in Complex Aircraft Structures. NASA Tech Brief LAR-13032.

PUBLICATIONS - 1985

Formal Reports

1. Childress, O. S., Jr. (Compiler): Helicopter Noise Reduction Program - 1984. NASA CP-2375, June 1985, 401 p.

2. DeLoach, R.; and Preisser, J. S.: Acoustic Source Location Using a Phase Slope Method. NASA TP-2505, November 1985, 47 p.

3. Hoad, D. R.; and Martin, R. M.: Background Noise Measurements from Jet Exit Vanes Designed to Reduce Flow Pulsations in an Open-Jet Wind Tunnel. NASA TM 86383, June 1985, 46 p.

4. Parrott, T. L.; Schein, D. B.; and Gridley, D.: Analytical Study of Acoustic Response of a Semireverberant Enclosure With Application to Active Noise Control. NASA TP-2472, December 1985, 46 p.

5. Roussos, L. A.: Noise Transmission Loss of a Rectangular Plate in an Infinite Baffle. NASA TP-2398, March 1985, 34 p.

6. Schoenster, J. A.: Fluctuating Pressures on Fan Blades of a Turbofan Engine - Flight Test Investigation. NASA TP-2381, February 1985, 24 p.

7. Seiner, J. M.; and Ponton, M. K.: Aeroacoustic Data for High Reynolds Number Supersonic Axisymmetric Jets. NASA TM-86296, January 1985, 68 p.

8. Watson, W. R.: A Method for Determining Acoustic-Liner Admittance in Ducts With Sheared Flow in Two Cross-Sectional Directions, NASA TP-2518, 1985, 37 p.

9. Willis, C. M.; Mayes, W. H.; and Daniels, E. F.: Effects of Propeller Rotation Direction on Airplane Interior Noise Levels. NASA TP-2444, July 1985, 32 p.

Quick-Release Technical Memorandums

10. Fields, J. M.; and Powell, C. A.: A Community Survey of Helicopter Noise Annoyance Conducted Under Controlled Noise Exposure Conditions. NASA TM-86400, March 1985, 186 p.

11. Patrick, H. V. L.: Investigation of Composite Material Property Requirements for Sonic Fatigue Research. NASA TM-87601, August 1985, 36 p.

12. Willshire, W. L., Jr.: Long Range Downwind Propagation of Low-Frequency Sound, NASA TM-86409, April 1985, 20 p.

Contractor Reports

13. Abrahamson, A. L.: An Evaluation of Proposed Acoustic Treatments for the NASA LaRC 4- x 7-Meter Wind Tunnel. (L-64517B Comtek.) NASA CR-172577, April 1985, 37 p.

14. Anderson, G. S.; Hayden, R. E.; Thompson, A. R.; and Madden, R.: Evaluation of the Feasibility of Scale Modeling to Quantify Wind and Terrain Effects on Low-Angle Sound Propagation. (NAS1-16521 Bolt Beranek and Newman, Inc. NASA CR 172488, January 1985, 124 p.

15. Burton, D. E.; Schlinker, R. H.; and Shenoy, R.: The Status of Analytical Helicopter Noise Prediction Methods. (NAS1-1716 United Technologies Research Center and Sikorsky Aircraft Division.) NASA CR-172606, August 1985, 125 p.

16. Fields, J. M.: Research on the Effect of Noise at Different Times of Day: Models, Methods, and Findings. (NAS1-16978 The Bionetics Corporation.) NASA CR-3888, April 1985, 82 p.

17. Fields, J. M.: Data on Noise Environments at Different Times of Day Around Airports. (NAS1-16978 The Bionetics Corporation.) NASA-CR-172612, June 1985, 55 p.

18. Fields, J. M.: The Timing of Noise-Sensitive Activities in Residential Areas. (NAS1-16978 The Bionetics Corporation.) NASA CR-177937, July 1985, 52 p.

19. Hayden, R. E.; Remington, P. J.; Theobald, M. A.; and Wilby, J. F.: Methods for Designing Treatments to Reduce Interior Noise of Predominant Sources and Paths in a Single engine Light Aircraft. (NAS1-16138 Bolt Beranek and Newman Inc.) NASA CR-172546, March 1985, 302 p.
20. Hellman, R. P.: Contribution of Tonal Components to the Overall Loudness, Annoyance, and Noisiness of Noise: relation Between Single Tones and Noise Spectral Shape. (NSG-1644 Boston University.) NASA CR-3892, May 1985, 150 p.
21. Huff, D. L.; and Shenoy, R. K.: Investigation of the Transonic Blade-Vortex Interaction Characteristics of Airfoil Sections Using ATRAN-2 and Euler Codes. (NS1-17146 Sikorsky Aircraft, United Technologies Corporation.) NASA CR-172604, July 1985, 124 p.
22. Liu, N-S.; and Shamroth, S. J.: On the Application of a Hairpin Vortex Model of Wall Turbulence to Trailing Edge Noise Prediction. NAS1-17249 Scientific Research Associates, Inc) NASA CR-177938, August 1985, 56 p.
23. Mahan, J. R.; and Fuller, C. R.: An Improved Source Model for Aircraft Interior Noise Studies. (NAG1-493 Virginia Polytechnic Institute and State University.) NASA CR-172490, February 1985, 160 p.
24. May, D. N.; Plotkin, K. J.; Selden, R. G.; and Sharp, B. H.: Lightweight Sidewalls for Aircraft Interior Noise Control. (NS1-17263 McDonnell Douglas Corporation.) NASA CR-172490, February 1985, 160 p.
25. Reich, F. R.; and Coleman, W. J.: Feasibility of an Optical Slip-Ring for High-Density-Data Communication Links. (NAS1-17930 Flow Industries, Inc.) NASA CR-172611, July 1985, 46 p.
26. Shepherd, K. P.: Detection of Low Frequency Impulsive Noise From Large Wind Turbine Generators. (NAS1-16978 The Bionetics Corporation.) NASA CR-172511, January 1985, 23 p.
27. Shepherd, K. P.; and Hubbard, H. H.: Sound Propagation Studies for a Large Horizontal Axis Wind Turbine. (NAS1-16978 The Bionetics Corporation and NAG1-166 The College of William and Mary.) NASA CR-172564, March 1985, 44 p.
28. Tomberlin, T. J.: Statistical Methods for Efficient Design of Community Surveys of Response to Noise: Random Coefficients Regression Models. (NAS1-16978 The Bionetics Corporation; Subcontractor: Thomas J. Tomberlin, Consultant.) NASA CR-177933, July 1985, 25 p.
29. Wilby, E. G.; and Pope, L. D.: Propeller Aircraft Interior Noise Model - Users' Manual for Computer Program. (NAS1-15782 Bolt Beranek and Newman Inc.) NASA CR-172425, January 1985, 58 p.
30. Yates, J. E.: Analysis of the Surface Load and Radiated Sound of a Vibrating Airfoil With Application to the Experiment of Brooks. (NAS1-17003 Aeronautical Research Associates of Princeton, Inc.) NASA CR-3864, January 1985, 144 p.

Journal Articles and Other Publications

31. Beyer, T. B.; Powell, C. A.; Daniels, E. F.; and Pope, L. D.: Effects of Acoustic Treatment on the Interior Noise of a Twin-Engine Propeller Airplane. *Journal of Aircraft*, Volume 22, No. 9, September 1985, 784-788.
32. Block, P. J. W.: Noise Radiation Patterns of Counter-Rotation and Unsteadily Loaded Single-Rotation Propellers. *Journal of Aircraft*, Volume 22, No. 9, September 1985, p. 776-783.
33. Brooks, T. F.; and Marcolini, M. A.: Scaling of Airfoil Self Noise Using Measured Flow Parameters. *AIAA Journal*, Volume 23, No. 2, February 1985, p. 207-213.
34. Dash, S. M.; Wolf, D. E.; Seiner, J. M.: Analysis of Turbulent Underexpanded Jets Part I: Parabolized Navier-Stokes Model, (SCIPVIS). *AIAA Journal* Volume 23, No. 4, April 1985, pp. 505-514.
35. Eversman, W.; Parrott, A. V.; Preisser, J. S.; and Silcox, R. J.: Contributions to the Finite Element Solution of the Fan Noise Radiation Problem. *Journal of Vibration, Acoustics, Stress, and Reliability in Design*, Volume 107 April 1985, p. 216-223.
36. Farassat, F.; and Myers, M. K.: Some Qualitative Results on the Thickness and Loading Noise of Rotating Blades. *Journal of Sound and Vibration*, Vol. 101, No. 2, 1985, pp. 262-266.
37. Fuller, C. R.: Monopole Excitation of Vibrations in an Infinite Cylindrical Elastic Shell Filled With Fluid. *Journal of Sound and Vibration*, Volume 96, No. 1, 1984, p. 101-110.
38. Grosveld, F. W. .; and Mixson, J. S.: Noise Transmission Through an Acoustically Treated and Honeycomb-Stiffened Aircraft Sidewall. *Journal of Aircraft*, Volume 22, No. 5, May 1985, p. 434-440.
39. Hardin, J. C.; and Mason, J. P.: A New Look at Sound Generation by Blade/Vortex Interaction. *Journal of Vibration, Acoustics, Stress, and Reliability and Design*, Volume 107, April 1985, p. 224-228.
40. Hariharan, S. I.; and Lester, H. C.: Acoustic Shocks in a Variable Area Duct Containing Near Sonic Flows. *Journal of Computational Physics*, Volume 58, No. 1, March 1985, p. 134-145.
41. Kibens, V.; and Wlezien, R. W.: Noise Reduction Mechanisms in Supersonic Jets With Porous Centerbodies. *AIAA Journal*, Vol. 23, No. 5, pp. 678-684, May 1985.
42. Martin, R. M.; Brooks, T. F.; and Hoad: Reduction of Background Noise Induced by Wind Tunnel Jet Exit Vanes. *AIAA Journal*, Vol. 23, No. 10, October 1985, p. 1631-1632.

43. Preisser, J. S.; Silcox, R. J.; Eversman, W.; and Parrott, A.V.: Flight Study of Induced Turbofan Inlet Acoustic Radiation With Theoretical Comparisons. Journal of Aircraft, Volume 22, No. 1, January 1985, p. 57-62.
44. Padula, S. L.; and Block, P. J. W.: Predicted Changes in Advanced Turbo-prop Noise With Shaft Angle of Attack. Journal of Propulsion and Power, Volume 1, No. 5, September - October 1985, p. 381-387.
45. Ribner, H. S.: Cylindrical Sound Wave Generated by Shock-Vortex Interaction. AIAA Journal, Vol. 23, No. 11, pp. 1708-1715, November 1985.
46. Seiner, J. M.; Dash, S. M.; and Wolf, D. E.: Analysis of Turbulent Underexpanded Jets, Part II: Shock Noise Features Using SCIPVIS. AIAA Journal, Volume 21, No. 5, May 1985, p. 669-677.
47. Tam, C. K. W.; Jackson, J. A.; and Seiner, J. M.: A Multiple-Scales Model of the Shock Cell Structure of Imperfectly Expanded Supersonic Jets. Journal of Fluid Mechanics, Volume 153, May 1985, p. 123-149.
48. Vaicaitis, R.; Grosveld, F. W.; and Mixson, J. S.: Noise Transmission Through Aircraft Panels. Journal of Aircraft, Volume 22, No. 4, April 1985, p. 303-310.
49. Vaicaitis, R.; and Mixson, J. S.: Theoretical Design of Acoustic Treatment for Noise Control in a Turboprop Aircraft. Journal of Aircraft, Volume 22, No. 4, April 1985, p. 318-324.
50. Wood, J. J.; and Leatherwood, J. D.: Meter Measures Ride Comfort. Automotive Engineering -- Testing and Instrumentation Issue, Volume 93, No. 6, June 1985, p. 50-56.
51. Yu, J. C.; and Fratello, D. J.: Measurement of Acoustic Shielding by a Turbulent Jet. Journal of Sound and Vibration, Volume 98, No. 2, 1985, pp. 183-212.
52. Zaman, K. B. M. Q.: Far-Field Noise of a Subsonic Jet Under Controlled Excitation. Journal of Fluid Mechanics, Volume 152, March 1985, p. 83-112.
53. Zaman, K. B. M. Q.; and Yu, J. C.: Power Spectral Density of Subsonic Jet Noise. Journal of Sound and Vibration, Volume 98, February 22, 1985, p. 519-537.

Meeting Presentations

54. Adelman, J. L.; and Hardin, J. C.: Vortex Studies Relating to Boundary Layer Turbulence and Noise. Presented at the ASME Winter Annual Meeting, November 17-22, 1985, Miami Beach, Florida. Proceedings pending.
55. Block, P. J. W.: Acoustics for Advanced Turboprop Aircraft. Presented at the Langley Symposium on Aerodynamics, April 23-25, 1985, Hampton, Virginia. NASA CP pending.
56. Farassat, F.: The Ffowcs Williams-Hawkins Equation - Fifteen Years of Research. Presented at the IUTAM Symposium on Aero- and Hydro-Acoustics, July 3-6, 1985, Lyon, France. To be published by Springer Verlag.

57. Grosveld, F. W.; and Metcalf, V. L.: Random Response and Noise Transmission of Composite Panels. Presented at the AIAA, ASME, et al., 26th Structures, Structural Dynamics, and Materials Conference, April 15-17, 1985, Orlando, Florida. AIAA Paper No. 85-0789-CP.
58. Hardin, J. C.; and Lamkin, S. L.: Computational Aeroacoustics - Present Status and Future Promise. Presented at the IUTAM Symposium on Aero- and Hydro-acoustics, July 3-6, 1985, Lyon, France. To be published by Springer Verlag.
59. McCurdy, D. A.: Comparison of Advanced Turboprop and Conventional Jet and Propeller Aircraft Flyover Noise Annoyance. Presented at the 110th Meeting of the Acoustical Society of America, November 4-8, 1985, Nashville, Tennessee.
60. *Metcalf, V. L.; and Grosveld, F. W.: Noise Transmission Characteristics of Aircraft Type Composite Panels. Presented at the 1985 SAE General Aviation Aircraft Meeting and Exposition, April 15-19, 1985, Wichita, Kansas. SAE Paper No. 850878.
61. Preisser, J. S.: Current Research in Acoustic Propagation at the NASA Langley Research Center. Presented at the University of Mississippi Symposium/Workshop on the Physics of Long Distance Sound Propagation and Coupling Into the Ground, February 13-16, 1985, New Orleans, Louisiana.
62. Schein, D. B.; and Parrott, T. L.: Effects of Source Separation and Phasing on Acoustic Power in a Semi-Reverberant Space With Applications to Active Noise Control. Presented at the 109th Meeting of the Acoustical Society of America, April 8-12, 1985, Austin, Texas. Abstract published in Journal of Acoustical Society of America, Volume 77, Supplement 1, Spring 1985, p. S-32.
63. Seiner, J. M.: Vortex Generated Breath Sounds in a Multi-Order Airway Model," Presented at the 38th ACEMB Meeting, Chicago, Illinois, September 30-October 2, 1985.
64. Silcox, R. J.; and Elliott, S. J.: Applicability of Superposition and Source Impedance Models of Active Noise Control Systems. Presented at the International Institute of Noise Control Engineering International Conference Noise Control Engineering, September 18-20, 1985, Munich, Germany.
65. Vaicaitis, R.; and Mixson, J. S.: Review of Research on Structureborne Noise and Vibration in Flight Structures. Presented at the AIAA, ASME et al., 26th Structures, Structural Dynamics, and Materials Conference, April 15-17, 1985, Orlando, Florida. AIAA Paper No. 85-0786-CP.
66. Wilby, J. F.; Mixson, J. S.; and O'Neal, R. L.: Flight Investigation of Cabin Noise Control Treatments for a Light Turboprop Aircraft. Presented at the 1985 SAE General Aviation Aircraft Meeting and Exposition, April 15-19, 1985, Wichita, Kansas. SAE Paper No. 850876.

*Army Structures Laboratory (AVSCOM)

67. Willshire, W. L., Jr.: Long Range Downwind Propagation of Low Frequency Noise. Presented at the University of Mississippi Symposium/Workshop on the Physics of Long Distance Sound Propagation and Coupling Into the Ground, February 13-16, 1985, New Orleans, Louisiana. In Proceedings, Volume 1, pp. 176-194.

68. Willshire, W. L., Jr.: Long Range Downwind Propagation of Low Frequency Noise. Presented at the 109th Meeting of the Acoustical Society of America, April 8-12, 1985, Austin, Texas. Abstract published in Journal of Acoustical Society of America, Volume 77, Supplement 1, Spring 1985, pp. S-91.

69. Wood, J. J.; and Leatherwood, J. D.: A New Ride Quality Meter. Presented at the SAE Vehicle Noise and Vibration Conference, May 15-17, 1985, Traverse City, Michigan. In Proceedings of Vehicle Noise and Vibration Conference, Paper No. 850981, p. 177-183.

70. Wood, J. J.; and Leatherwood, J. D.: A New Ride Quality Meter. Presented at the 1985 SAE International Off-Highway & Powerplant Congress & Exposition, September 9-12, 1985, Milwaukee, Wisconsin.

71. Wood, J. J.; and Leatherwood, J. D.: A New Ride Quality Meter. Presented at the 85th SAE Truck and Bus Meeting -- Exposition, December 9-12, 1985, Chicago, Illinois.

Technical Talks

72. Booth, E. R., Jr.: Flow Visualization in an Unsteady, Periodic, Flow-field-The Two Dimensional Blade-Vortex Interaction Experiment. Presented at the NASA 21st Annual Subsonic Aerodynamic Testing Association (SATA) Meeting May 14-16, 1985, Williamsburg, Virginia.

73. Golub, R. A.: ROTONET Update. Presented at the NASA/AHS Helicopter Noise Reduction Program 3rd Annual Review, October 8-10, 1985, Stratford, Connecticut.

74. Pao, S. P.: Rotorcraft Source Noise Research in the Aeroacoustics Branch. Presented at the NASA/AHS Helicopter Noise Reduction Program 3rd Annual Review, October 8-10, 1985, Stratford, Connecticut.

75. Martin, R. M.: Main Rotor Interaction Noise Experiment. Presented at the NASA/AHS Helicopter Noise Reduction Program 3rd Annual Review, October 8-10, 1985, Stratford, Connecticut.

76. Yu, J. C.: DNW Main Rotor Noise Experiment. Presented at the NASA/AHS Helicopter Noise Reduction Program 3rd Annual Review, October 8-10, 1985, Stratford, Connecticut.

77. Yu, J. C.: Acoustic Treatment Feasibility Study of Langley 4- by 7-Meter Wind Tunnel. Presented at the NASA/AHS Helicopter Noise Reduction Program 3rd Annual Review, October 8-10, 1985, Stratford, Connecticut.

78. Morgan, H. G.: NASA Langley Research Center Planned Rotorcraft Acoustics Research. Presented at the NASA/AHS Helicopter Noise Reduction Program 3rd Annual Review, October 8-10, 1985, Stratford, Connecticut.
79. Golub, R. A.: ROTONET Implemented Capabilities, Planned Capabilities and Status. Presented at the Government/Industry Working Group on Rotorcraft Noise Meeting, April 18-19, 1985, Washington, DC.
80. Childress, O. S., Jr.: 500E Flight Test to Provide Data Base for Evaluating ROTONET Predictions: Requirements, Plans and Status. Presented at the Government Industry Working Group on Rotorcraft Noise Meeting, April 18-19, 1985, Washington, DC.
81. Lamkin, S. L.; and Hardin, J. C.: Aeroacoustic Computation of Free Shear Layer Flow. Presented at the SIAM Fall Meeting, October 28-30, 1985, Tempe, Arizona.
82. Morgan, H. G.: Noise Control Technology for Business Aircraft. Presented at the 1985 SAE General Aviation Aircraft Meeting and Exposition, April 15-18, 1985, Wichita, Kansas.
83. Seiner, J. M.: Advances in High Speed Jet Aeroacoustics, Lecture given at Rutgers University, March 5-7, 1985.
84. Stephens, D. G.: Aircraft Interior Noise Reduction. Presented at the EAA Convention and Fly-In, July 26 - August 2, 1985, Oshkosh, Wisconsin.
85. Yu, J. C.: Acoustic Treatment Feasibility Study of NASA LaRC 4- by 7-Meter Wind Tunnel for Rotorcraft Aeroacoustics Testing. Presented at the NASA 21st Annual Subsonic Aerodynamic Testing Association (SATA) Meeting, May 14-16, 1985, Williamsburg, Virginia.

Computer Programs

No computer programs.

Tech Briefs

86. Watson, W. R.: Acoustic-Liner Admittance in a Rectangular Duct With Grazing Flow. NASA Tech Brief LAR-13399.

Patents

No patents.

CONCLUDING REMARKS

This overview has been intended to portray the scope, character, and direction of the Acoustics Division and its program. The program will

continue to evolve in response to changing research needs, always seeking to focus upon the most important aerospace problems requiring expertise from the discipline of acoustics. The sampling of technical accomplishments and list of publications is representative of the technology from the program over the past two years. Those interested in further details of particular technical accomplishments are encouraged to contact the individuals identified with each project.

REFERENCES

1. National Aeronautical R & D Goals: Technology for America's Future: Executive Office of the President, Office of Science and Technology Policy, March 1985.
2. Research and Technology Objectives and Plans Summary, FY 86; NASA TM-87504, January 1986.
3. Hubbard, Harvey J.; and Powell, Clemans A.: Acoustic Facilities for Human Factors Research at NASA Langley Research Center. NASA TM 81975, 1981.
4. Hubbard, Harvey H.; and Manning, James C.: Aeroacoustic Research Facilities at NASA Langley Research Center. NASA TM 84585, 1983.

ACOUSTICS DIVISION

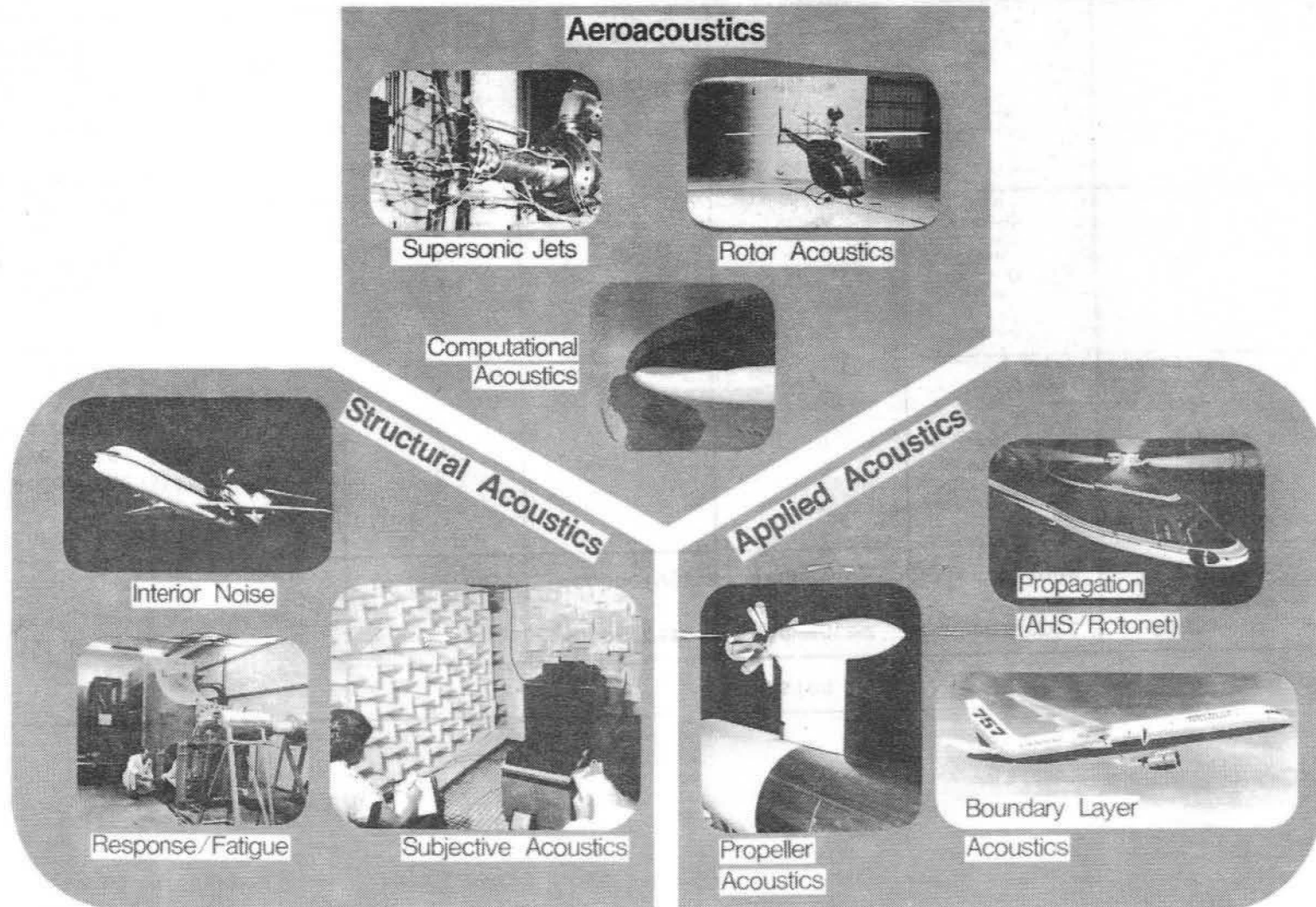


Figure 1.- Conceptual illustration of the acoustics program at Langley Research Center.

Discipline Areas	Division Goals				
	Acoustics Technology	Rotorcraft Technology	Advanced Propeller Technology	Hypersonic Technology	Space Station Technology
Structural Acoustics					
Interior Acoustics	0	0	0		0
Active Noise Control	0	0	0		0
Sonic Fatigue	0		0	0	
Subjective Acoustics			0	0	0
Aeroacoustics					
Jet Acoustics	0			0	
Rotor Acoustics	0	0			
Computational Acoustics	0	0	0	0	
Applied Acoustics					
Boundary Layer Acoustics	0			0	
Propeller Acoustics	0		0		
Atmospheric Propagation	0	0	0		
Helicopter Acoustics		0			

Figure 2.- Technical goals supported by discipline areas.

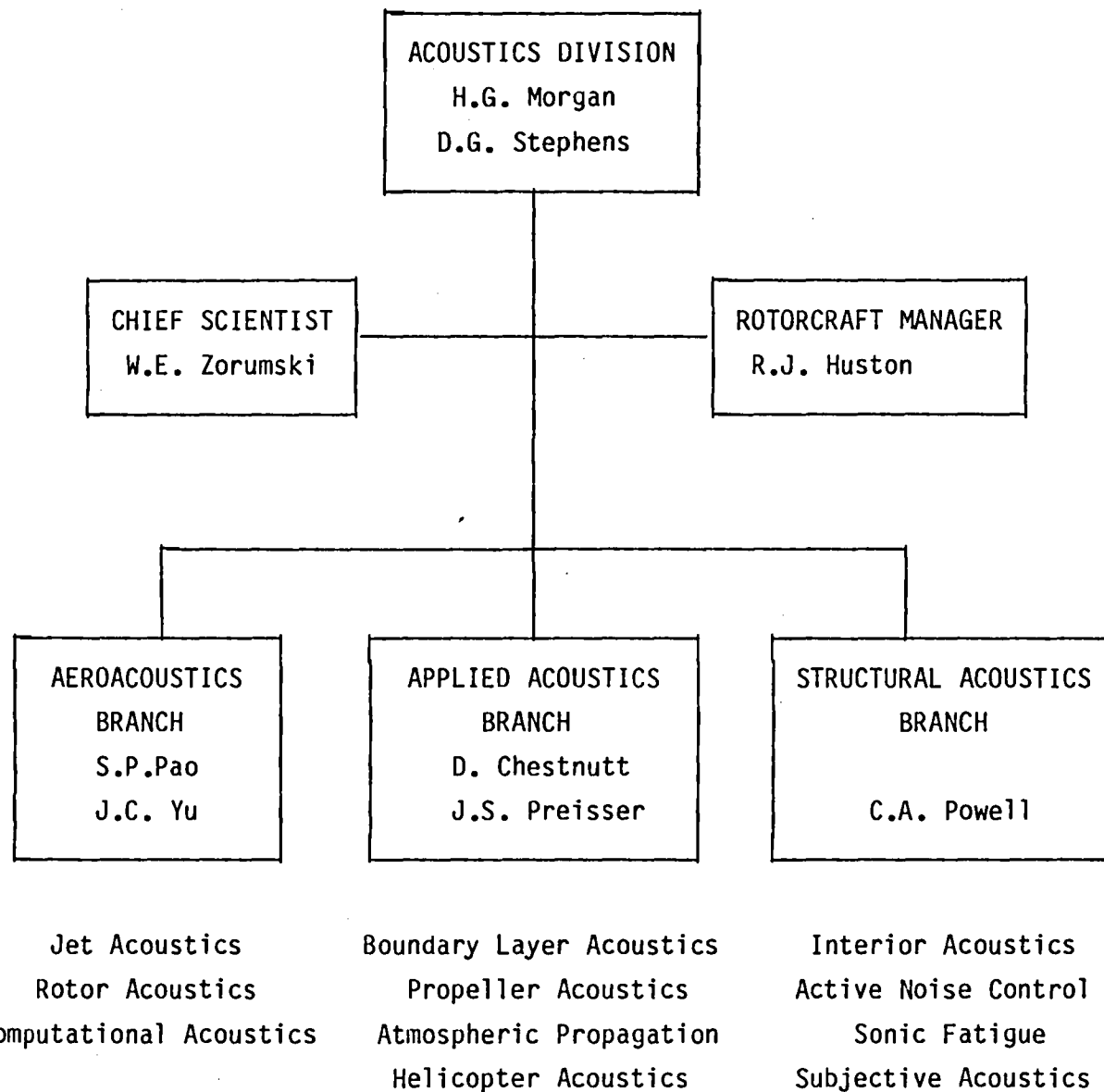


Figure 3. - Organization of the Acoustics Division.

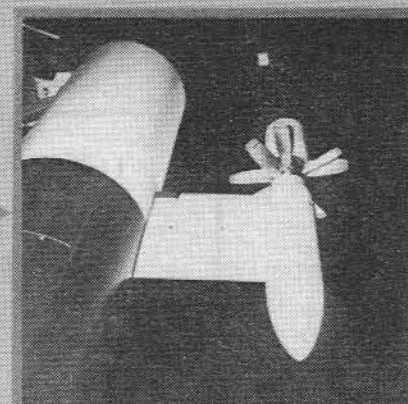
ACOUSTICS RESEARCH FACILITIES



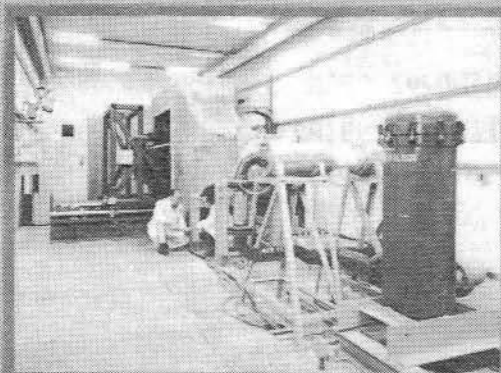
**TRANSMISSION LOSS
APPARATUS**



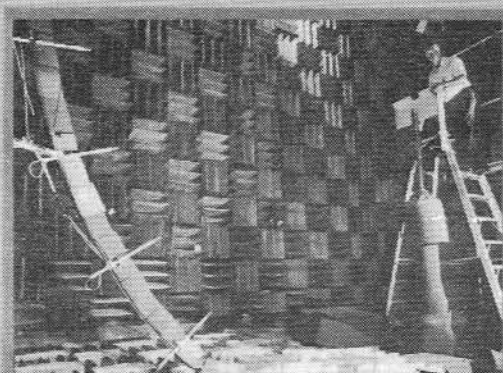
**AIRCRAFT NOISE
REDUCTION LABORATORY**



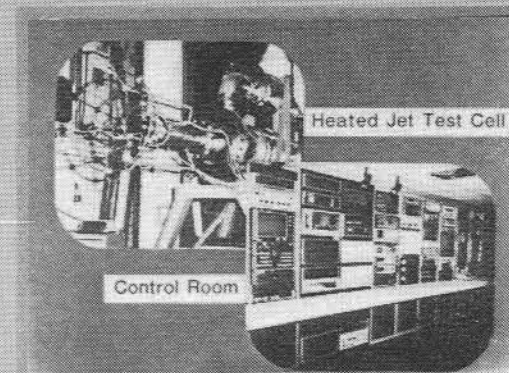
**QUIET FLOW
FACILITY**



**THERMAL ACOUSTIC
FATIGUE APPARATUS**

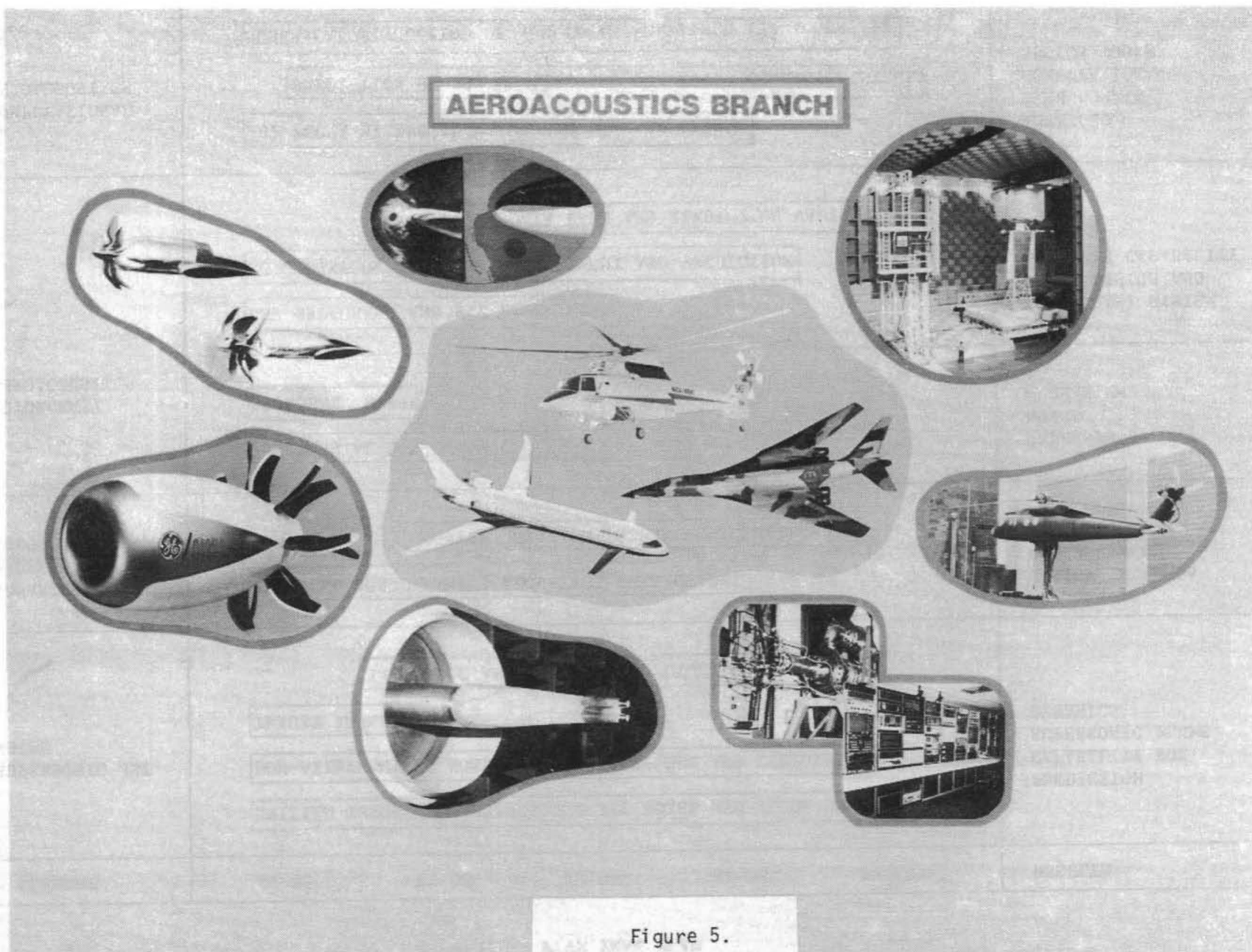


**ANECHOIC NOISE
FACILITY**



**JET NOISE
LABORATORY**

Figure 4.



AEROACOUSTICS BRANCH, AcoD

FIVE YEAR PLAN

ELEMENT	FY 85	FY 86	FY 87	FY 88	FY 89	RESULTS
SUPERSONIC JET NOISE		<div>UNIFIED THEORY FOR SUPERSONIC JET NOISE AND PLUME DYNAMICS</div> <div>NON-AXISYMMETRIC NOZZLE TECHNOLOGY: HOT AND VECTORED</div> <div>THRUST REVERSER</div> <div>TRANSONIC AND SUPERSONIC FLIGHT SIMULATION</div>				PREDICTION CAPABILITY FOR SUPERSONIC PLUME DYNAMICS
ADVANCED PROPELLER ACOUSTICS		<div>ADVANCED AERODYNAMICS/ACOUSTICS PREDICTION</div> <div>COUNTER ROTATION PROPELLER ACOUSTICS</div>				DESIGN CRITERIA FOR ADVANCED PROPELLERS
ROTORCRAFT AEROACOUSTICS		<div>FUNDAMENTAL BVI DYNAMICS AND ACOUSTICS</div> <div>BROADBAND NOISE</div>				UNDERSTANDING NOISE MECHANISM
		<div>DNW BROADBAND AND BVI EXPERIMENT</div> <div>ROTOR INFLOW AND WAKE MEASUREMENT AND PREDICTION</div> <div>ROTOR NOISE DATA BASE AND PREDICTION VALIDATION</div>				ROTORCRAFT SYSTEM NOISE DESIGN AND ANALYSIS CAPABILITY
COMPUTATIONAL AEROACOUSTICS		<div>JET PLUME MIXING IN TRANSONIC FORWARD FLIGHT</div> <div>PREDICTION OF SR, CR-ATP, AND UDF NOISE CHARACTERISTICS</div> <div>NUMERICAL SIMULATION OF NONLINEAR NEARFIELD ATP ACOUSTICS</div>				ADVANCED TIME DOMAIN COMPUTATIONAL DESIGN TOOLS

Figure 6.

A NEW TECHNIQUE FOR REMOVAL OF CONTAMINATION FROM AIRFOIL BROADBAND NOISE SPECTRA

Michael A. Marcolini
Aeroacoustics Branch
Extension 2645

Research Objective - Helicopter rotor blade broadband noise can be a dominant source under certain flight conditions. To quantify the various broadband noise mechanisms, experiments have been conducted on different airfoil sections in the ANRD Anechoic Flow Facility. In addition to the expected dominant trailing edge noise sources, an additional source at the leading edge was present for the airfoils with smaller chords. This source was due to the airfoils' response to inflow turbulence in the boundary layer of the test section and thus extraneous to the phenomena of interest. A novel technique to remove this contamination from the data was needed.

Approach - In past experiments, a cross-spectral method between two different microphone signals was used to extract the trailing edge broadband noise spectrum from background noise by assuming that trailing edge noise is the dominant coherent noise source. However, any leading edge contamination, if present, is included in these spectra also. The technique developed in this study makes use of the fact that the extraneous leading edge noise source is independent of the trailing edge noise source. Therefore, the cross-correlation R_{AB} is the superposition of the correlations from each of the sources. By combining the correlation with successive time-shifted versions of itself, the desired component may be extracted. This iterative technique is mathematically correct. The Fourier transform of that desired portion recover the power spectral density (PSD) of the noise source.

Accomplishment Description - Using the new technique, the trailing edge (TE) broadband noise component was successfully separated from the leading edge (LE) component. The figure on the left shows the iterative process for a two inch chord airfoil. The arrows indicate the components. Moving from bottom to top, the LE noise component is shifted away, while the TE noise component stabilizes in both amplitude and shape. The figure on the right shows the corresponding spectra. The contaminated PSD, obtained by the previous cross-spectral method, contains both noise sources. With the new technique, the PSD stabilizes and represents the trailing edge broadband noise free from contamination.

Future Plans - This technique will be applied to the existing data to obtain trailing edge noise spectra free from contaminations.

Figure 7(a).

A NEW TECHNIQUE FOR REMOVAL OF CONTAMINATION FROM AIRFOIL BROADBAND NOISE SPECTRA

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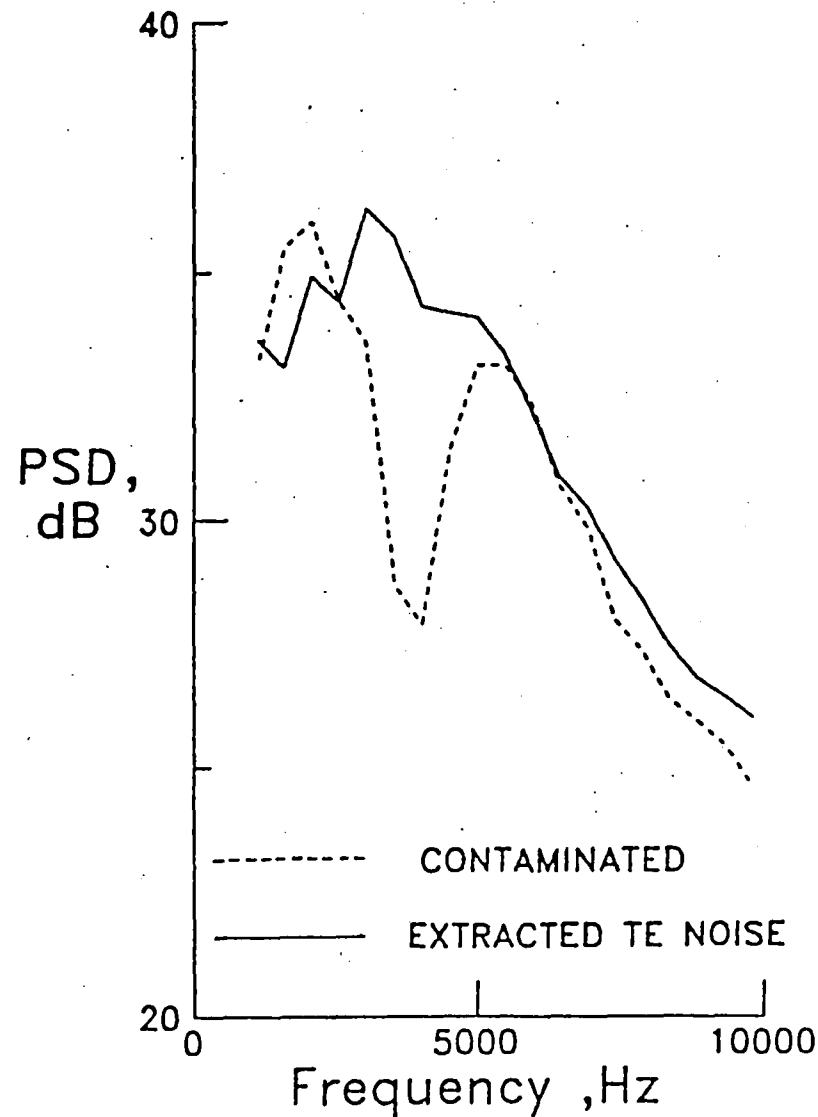
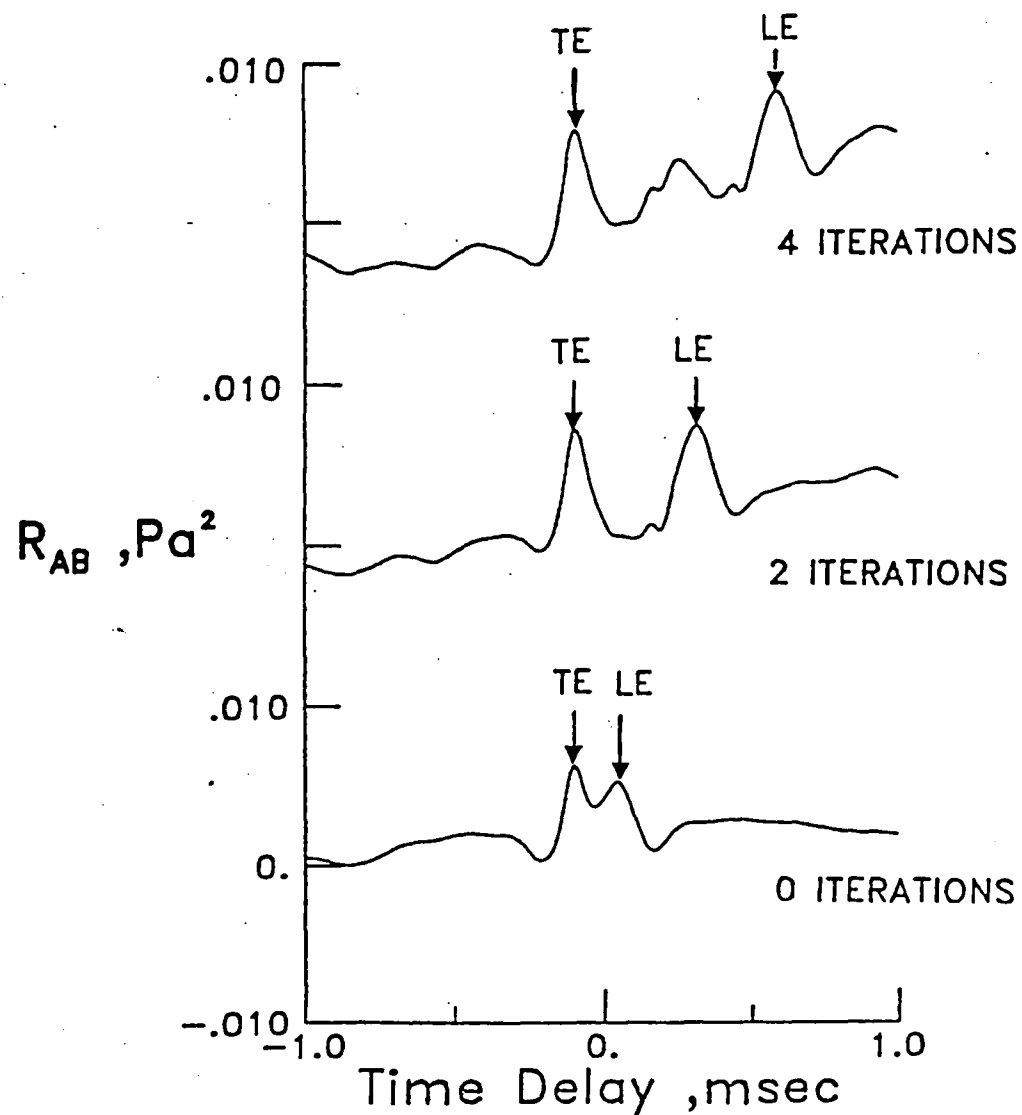


Figure 7(a).- Concluded.

SCALING OF SURFACE PRESSURE SPECTRA FOR TURBULENT BOUNDARY LAYERS

T. F. Brooks
Aeroacoustics Branch
Extension 2645

Research - A primary source of rotor broadband noise is the interaction between the blade and its boundary layer turbulence. This noise can be predicted if enough is known about the fluctuating surface pressure existing on the blade. The purpose of the present study is to examine the relationship between the boundary layer flow structure and the pressure field, as well as develop a predictive capability for the pressures through scaling.

Approach - Measurements are being made in the closed test section of a wind tunnel at Virginia Polytechnic and State University by Professor R. L. Simpson (Principal Investigator for NASA Langley Grant NAG-1-446). The measurements are to determine spectra and wavespeeds for tunnel wall pressure fluctuations and corresponding velocity fluctuations. A sideview schematic is shown of the test section where the flow is in the x direction and a separated boundary layer condition is illustrated. The top tunnel wall can be repositioned to regulate the tunnel's mean flow and pressure gradient distribution, thus controlling the boundary layer development. In addition, the active flow control ports can also be used to control the tunnel boundary layer through suction or blowing. The surface pressures are measured with microphones through small pinhole openings on the bottom tunnel wall. Hot-wire measurements are being used to define the boundary layers for several zero pressure gradient, favorable pressure gradient, and adverse pressure gradient cases. Of particular interest are boundary layer integral parameters as well as shear stress distributions to permit the study of scaling laws for the pressure spectra.

Accomplishment Description - Most of the initial measurements have been for a separated boundary layer. The figure shows surface pressure fluctuation spectra at different streamwise locations (different symbols), all within the separated boundary layer region. The function $F(f)$ is a pressure spectrum normalized with respect to total amplitudes, presented as a function of Strouhal number where f is frequency, δ^* is the displacement thickness, and U_∞ is the free stream velocity. The spectral similarity is demonstrated for frequencies near and beyond the Strouhal peak. At frequencies below the peak the spectral levels are relatively less for measurement locations farthest from the flow detachment region (just upstream of $x=3.1m$). The spectral trends are bounded by lines with frequency dependence between f^1 and $f^{2.5}$ for the two most separated sensor locations. In addition to the results shown here, preliminary data indicate that spectral amplitude scaling may be more successfully based on maximum Reynolds shear stress and its location from the surface, than based on freestream dynamic pressure as traditionally done in the literature.

Figure 7(b).

SCALING OF SURFACE PRESSURE SPECTRA FOR TURBULENT BOUNDARY LAYERS

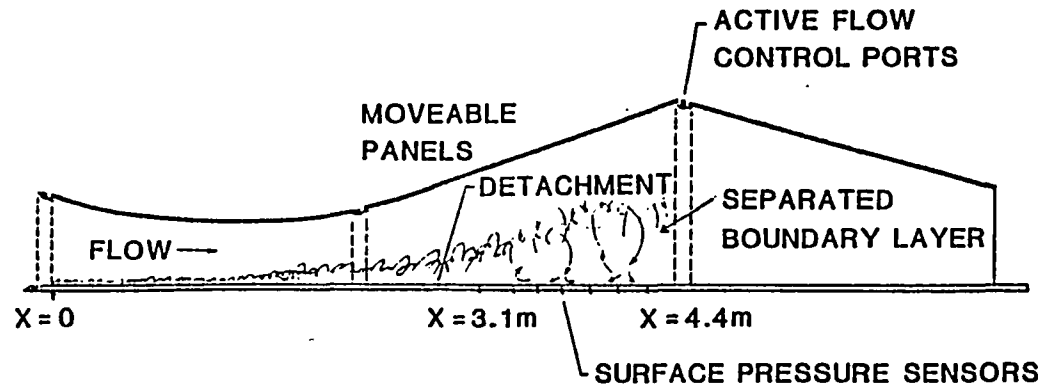
CONTINUED

Future Plans - The investigation will continue at VPI&SU. The examination of scaling laws will be aided by what should be a broad data base of boundary layer parameters corresponding to measured pressure spectra and convection velocities. With regard to NASA Langley plans, the scaling results of the study will be utilized along with boundary layer calculation methods to help accurately specify the surface pressure fluctuation characteristics for rotor blades. This would produce more accurate predictions of helicopter broadband noise.

Figure 7(b).- Continued.

SCALING OF TURBULENT BOUNDARY LAYER PRESSURE SPECTRA

TEST SECTION OF WIND TUNNEL



SURFACE PRESSURE SPECTRUM SCALING

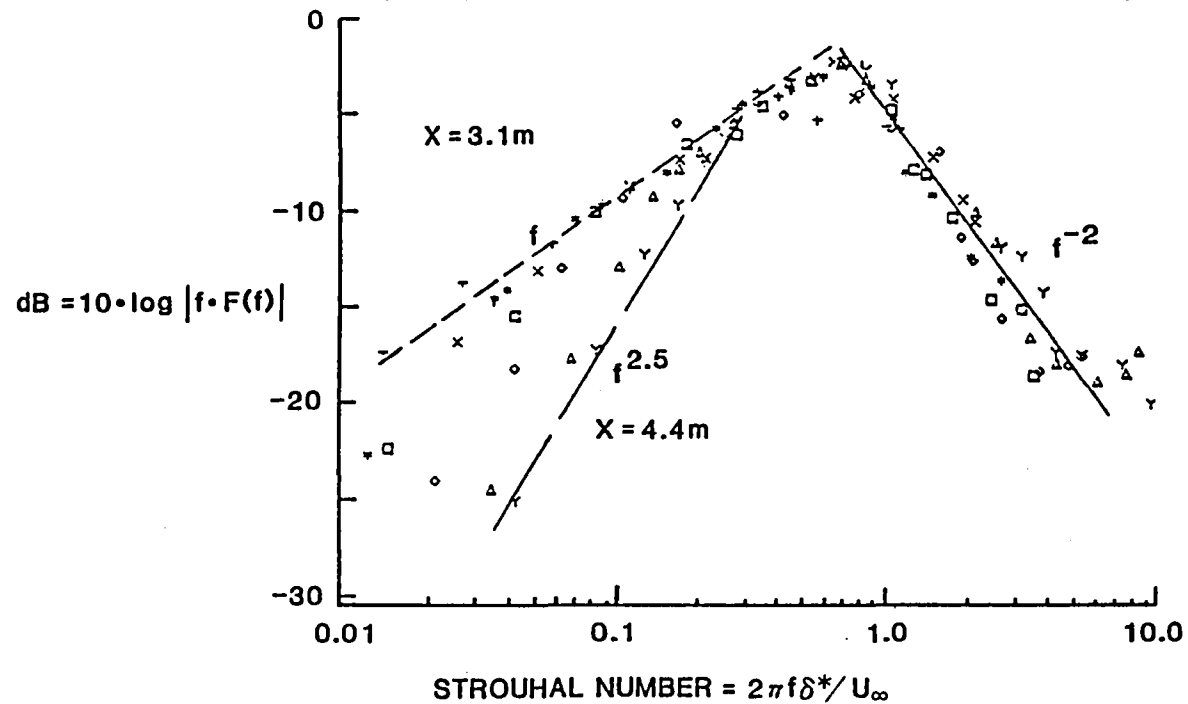


Figure 7(b).- Concluded.

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TIP VORTEX FORMATION NOISE

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Aeroacoustics Branch
Extension 2645

Research Objective - It has been shown that the rotor blade tip region can contribute significantly to high frequency broadband noise. The self noise mechanism believed responsible is trailing edge noise due to the three-dimensional vortex flow existing near the tip of the lifting blades. Although some analytical modeling has been developed under NASA sponsorship, there has been no significant guidance provided by experiment for the development of quantitative prediction methods. The present study is the first to isolate tip vortex noise in a quantitative manner.

Approach - Stationary airfoil models of rectangular planform with rounded tips were tested in the ANRD Anechoic Flow Facility. The "three-dimensional" models were each mounted on a sideplate in the open jet. Two-dimensional model tests, which employed two sideplates, were made to correspond to the same model chords (2, 4, 6, 9, and 12 inches), angles of attack (0° , 5.4° , 10.8° , and 14.4°), and tunnel flow velocities (39.6, 71.3 m/s). For the test cases considered the three-dimensional models produce both tip vortex and turbulent boundary layer trailing-edge noise, while the two-dimensional models produced only the latter. The tip vortex spectral data is obtained by a method based on comparisons of corresponding two- and three-dimensional test results. While the data processing is extensive, utilizing microphone cross-correlation and cross-spectral methods, the end result for each test case is a single spectrum which is corrected for shear layer diffraction and source directivity effects. The spectral results for the cases are used to examine quantitative scaling laws for the noise mechanism.

Accomplishment Description - The data figure shows one-third octave spectra for a six-inch chord NACA 0012 airfoil at three non-zero angles of attack for a single tunnel speed. At zero angle of attack the tip vortex noise mechanism is absent. Tip vortex noise is seen to have a wide broadband hump spectral character. The spectral levels are normalized as indicated by the tunnel velocity U , maximum velocity in the tip vortex U_m , a measure of the tip vortex formation region size represented by λ , and the noise field observer distance R . The sketch shown illustrates the geometry of the airfoil tip region where the tip vortex forms. The frequency is postulated to scale on a "Strouhal" basis with the vortex characteristics U_m and λ , which are approximated here. This scaling procedure has an analytical basis and has found some success in collapsing spectral data for a number of test cases. Although the scaling procedure is still under review, the actual attainment of quantitative spectra of tip vortex noise is accomplished for a large range of airfoil sizes, angles of attack, and tunnel velocities.

Figure 7(c).

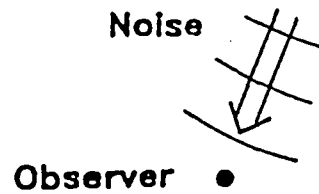
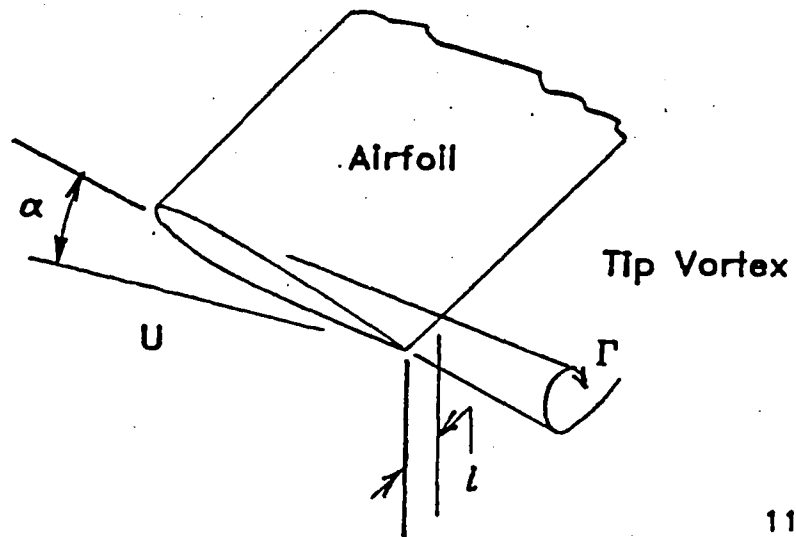
TIP VORTEX FORMATION NOISE

CONTINUED

Future Plans - Examination of scaling laws will continue by utilizing the spectral data base. Interpretation of the data will be aided by a three-dimensional flow analysis, incorporating open wind tunnel corrections, as well as a number of hot wire measurements made in the tip regions of the test models. The end result of the study should be a quantitative prediction capability for the tip vortex formulation noise mechanism and its installment in a complete helicopter noise prediction program, ROTONET.

Figure 7(c).- Continued.

TIP VORTEX FORMATION NOISE



$$SPL_{1/3}(f)$$

$$-10 \log [U^2 U_m^3 l^2 R^{-2}]$$

SCALED SPECTRA

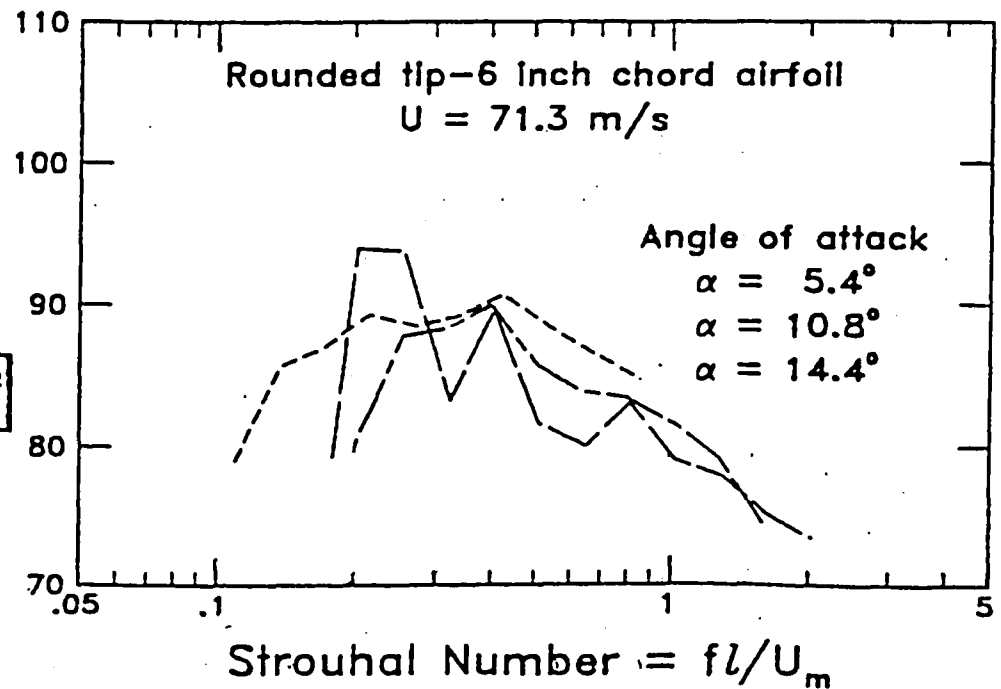


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MAIN ROTOR IN-FLOW TURBULENCE MEASUREMENT

Michael A. Marcolini
Aeroacoustics Branch
Extension 2645

Research Objective - During takeoff and landing of a helicopter, the ingestion of atmospheric turbulence by the main rotor can be a dominant source of helicopter noise at lower frequencies. Although it is understood qualitatively how turbulence can be ingested into the rotor and radiate noise when chopped by the blades, it is very difficult to accurately predict this noise. The primary difficulty lies in the fact that very little is known about the ingested turbulence characteristics. Therefore, the objective of the present experimental study is to quantify the needed turbulence properties above the main rotor disk of a full scale helicopter.

Approach - As a part of the NASA/AHS National Rotorcraft Noise Reduction Program, Hughes Helicopter, Inc., proposed a task to examine noise radiation from the various components of a Hughes 500 helicopter. To accomplish this, the engine, main rotor, and two- and four-bladed tail rotors were to be tested both together and separately. This test was to be performed on an outdoor whirl stand at Hughes' Culver City plant. The proposed experiment offered a unique opportunity for a cooperative research program to examine specific critical areas of rotor noise generation using a full scale helicopter. Modifications were therefore proposed by NASA/LaRC to the Hughes' original test plan to include hot-film measurements to be made above the main rotor disk. The specific objective was to quantify both the mean and fluctuating components of the main rotor inflow directly above the rotor disk. These measurements are essential to provide the required input data base for verifying the in-flow turbulence ingestion noise model developed by UTRC under a contract. NASA/LaRC was responsible, in conjunction with Hughes, for the planning and execution of the hot-film measurements and also to participate in the planning of the acoustic measurements. The attached photograph shows the experimental set-up with the cable/trolley system used to traverse the hot-film probes. This arrangement enabled laboratory-type measurement of turbulent quantities with high precision within 5 chord lengths of the rotor disk.

Accomplishment Description - Hot-film data were acquired at two main rotor speeds at each of two operating thrusts. In addition to the turbulence intensities, the axial turbulence length scales were measured using the autocorrelation of the fluctuating signal from one probe and the measured mean flow, and the radial length scales were measured by moving one probe with respect to the other. At each test condition, measurements were made with the fixed probe at five different radial stations. The test program was completed by the end of June 1985. The test took about 10 weeks out of which 3 weeks were spent in obtaining the hot-film data. Quick-look, on-line analysis indicates that both the acoustic and hot-film data are of good quality.

Figure 7(d).

MAIN ROTOR IN-FLOW TURBULENCE MEASUREMENT

CONTINUED

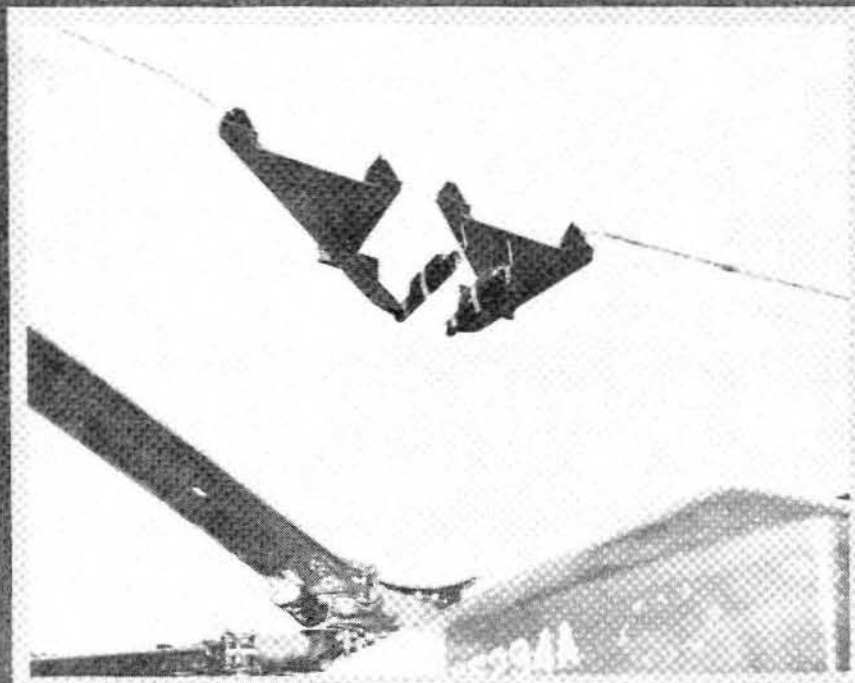
Future Plans - It is planned that both NASA and Hughes will analyze the data, with NASA's focus being on the hot-film measurements although NASA is to receive a copy of all data tapes. These data are anticipated to have great impact on the understanding and prediction development for helicopter in-flow turbulence ingestion noise.

Figure 7(d).- Continued.

MAIN ROTOR INFLOW TURBULENCE EXPERIMENT

MEASURED QUANTITIES

- Mean Flow & Turbulence Intensity
- Radial & Axial Length Scale



TWO PROBE TRAVERSING SYSTEM



SINGLE HOT FILM SENSOR

(Temperature Compensated)

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CHARACTERIZATION OF TWO DIMENSIONAL BLADE-VORTEX INTERACTION

E. R. Booth, Jr.
Aeroacoustics Branch
Extension 2645

Research Objective - Blade-Vortex Interaction (BVI) is the source mechanism of a particularly intense and impulsive type of helicopter noise. Although the dominance of BVI noise in certain flight regimes is well established, the detailed aerodynamic process of blade-vortex interaction is still poorly understood. This study was designed to examine the near field unsteady aerodynamic interaction between a vortex and a blade in a geometry representative of the most severe BVI.

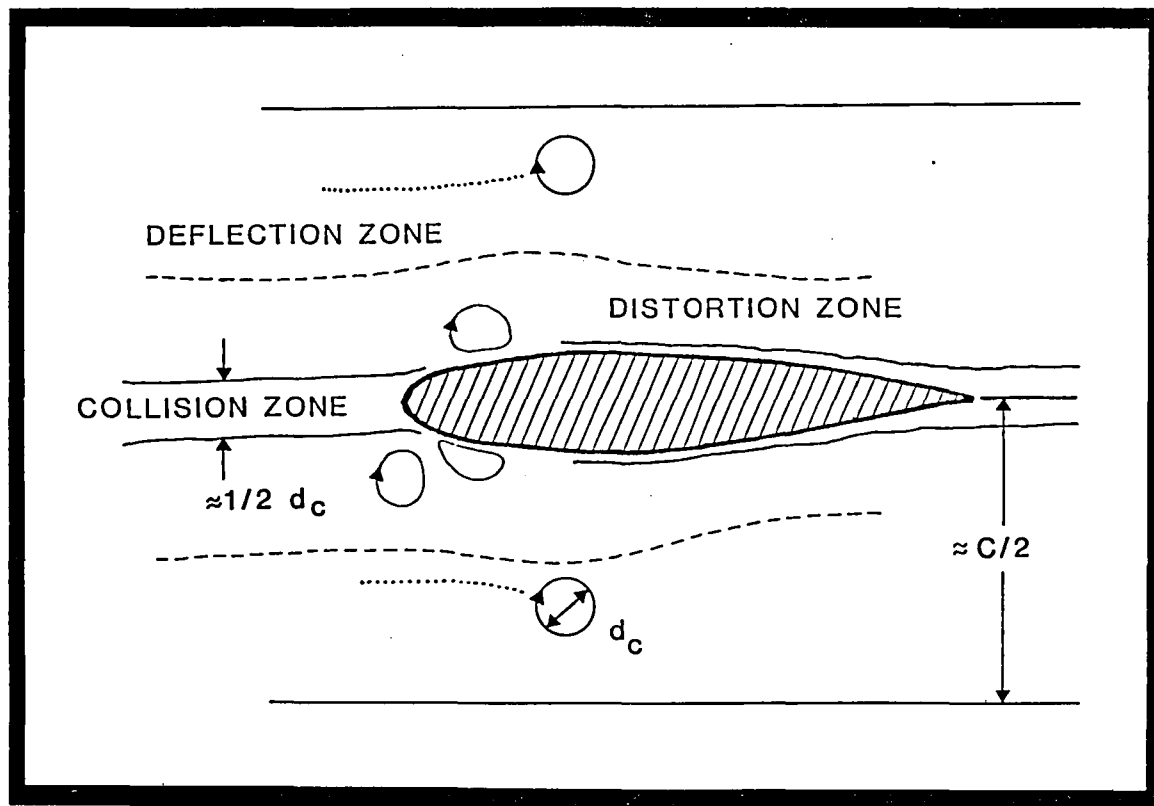
Approach - The aerodynamic phenomenon of BVI was examined through flow visualization. The test apparatus consisted of a two dimensional test section with a vortex generator upstream of a rotor blade section model. The vortex generator, an oscillating airfoil, created a vortex wake composed of alternating vortices orthogonal to the freestream velocity which impinged on the blade model parallel to the blade span. The vortex structure, rendered visible by smoke emitted from the vortex generator, was recorded optically utilizing phase-locked photography. Data acquired for several blade locations and angles of attack were digitized to allow analysis of vortex trajectories and detailed features of the interaction process.

Accomplishment Description - Analysis of the data resulted in the qualitative characterization of the close encounter region as schematically depicted in the figure. Representative photographs of BVI in each zone are included in the figure. The region within a half blade chord length, $c/2$, above and below the blade is the close encounter region, outside of which the blade has little or no effect on the trajectory or structure of the vortex core. Inside this region is the deflection zone, where the blade deflects the trajectory, but causes no significant distortion of the vortex core (diameter d_c). The distortion zone, where the dominant feature of the interaction is the distortion of the vortex core, lies inside the deflection zone. Finally, in the collision zone, a small region surrounding the blade stagnation streamline, the interaction features vortex core severing by the blade and the viscous interaction between the incident vortex and boundary layer vorticity. The most severe BVI, then, is one where vortex core disruption is important. The relatively small size of the interaction zones also emphasizes the accuracy to which the unsteady rotor wake geometry must be known to predict BVI noise.

Future Plans - Future research into two dimensional BVI will include measurement of unsteady blade leading edge pressure during encounter with vortex structures in all close encounter zones. Also planned are measurement of the vorticity fields of the vortex structures as well as a preliminary look at three dimensional BVI.

Figure 7(e).

2-D BVI ENCOUNTER ZONES



DEFLECTION ZONE



DISTORTION ZONE



COLLISION ZONE

Figure7(e).- Concluded.

THE PREDICTION OF NOISE OF ADVANCED PROPELLERS BASED ON A NEW ACOUSTIC FORMULATION

F. Farassat
Aeroacoustics Branch
Extension 4308

Research Objective - To predict the noise of advanced high speed propellers using a new acoustic formulation. The new formulation was derived to improve the accuracy and speed of computation of earlier formulations.

Approach - The theoretical pressure signature and spectrum from the new formulation are compared with measured data collected in an anechoic tunnel. Further comparisons are made with theoretical results from an earlier formulation.

51 Accomplishment Description - A computer code based on the new mathematical result was developed which retains the best features of an earlier code. The inputs to this code are the blade geometry, motion and surface pressures. The blade surface is divided into panels first. For a given observer position and time, the emission time of the panel center is calculated. If the Mach number in the radiation direction M_r at this time is subsonic an efficient noise prediction formula (VERTICA, Vol. 7, 1983) is used for the sound from the panel. For transonic and supersonic M_r , the new formulation is used. The new result consists of surface integrals over the high speed portion of the blade and line integrals over the leading edge, trailing edge and shock traces on the blade. Earlier this result was validated for a dipole distribution over a stationary disk. The results compared very well with those from a well known solution. In the present analysis, an example from NASA TP-1662 (July 1980) by Nystrom and Farassat is worked out with identical inputs to the new computer program as those of TP-1662. The attached figure shows the old and the new theoretical results plotted against measured pressure signature. It is seen that the high frequency oscillations due to numerical errors in the old calculation are removed and the agreement with measured signature is considerably improved. A corresponding better agreement is also observed for pressure spectrum, which is not shown in the figure. Because of several major improvements in the present code, the execution time on the computer is substantially better than the old code.

Future Plans - Further improvements in the structure and algorithms of the code are expected. More comparisons with measured data and prediction of contrarotating propeller noise are planned.

Figure 8(a).

COMPARISON OF PREDICTED AND MEASURED PRESSURE SIGNATURE FOR AN ADVANCED SUPERSONIC PROPELLER - SR-3, $M_t = 1.17$

(NASA TP 1662, Example 14)

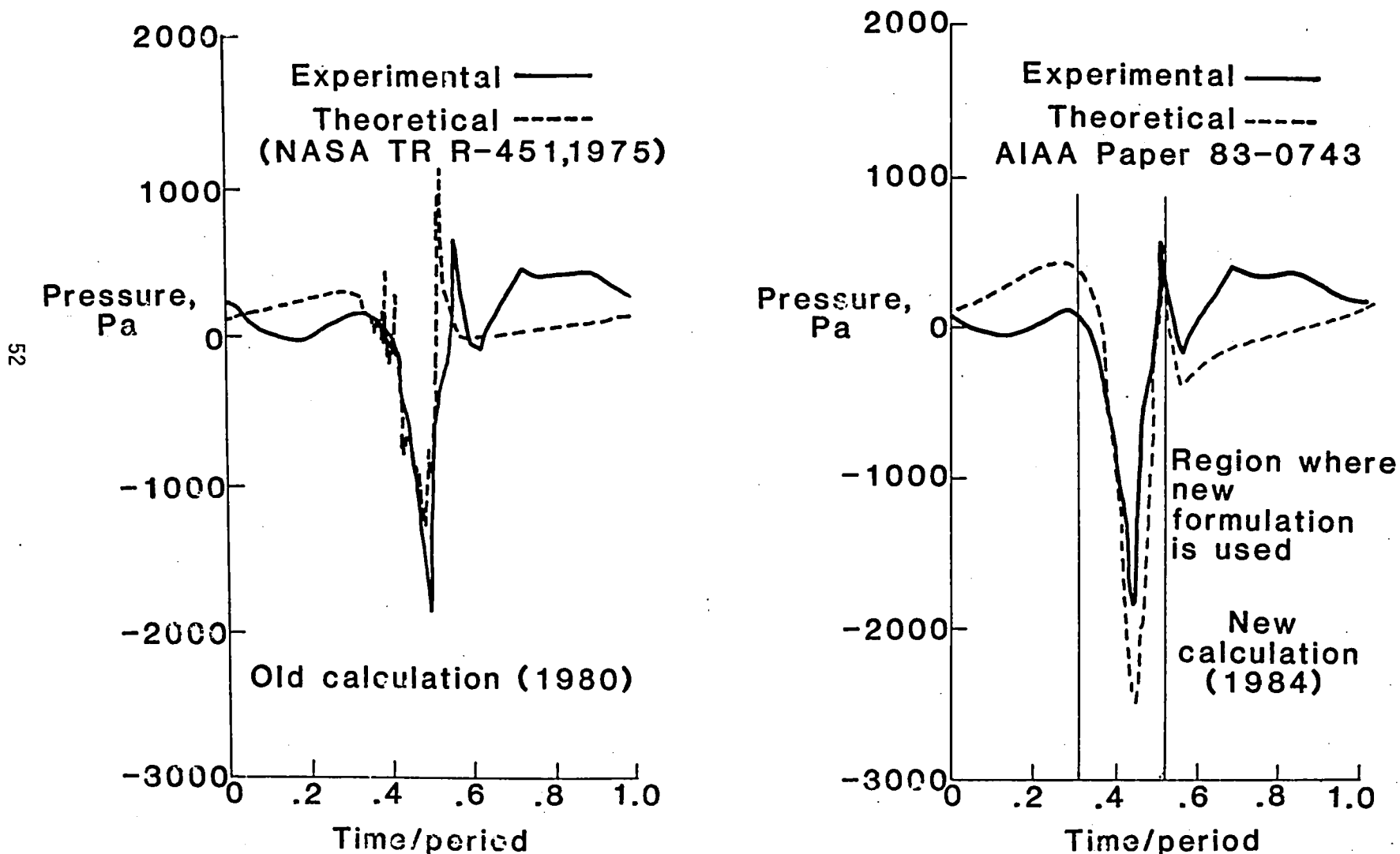


Figure 8(a).- Concluded.

THE MEAN SURFACE APPROXIMATION TO A FORMULATION FOR THE PREDICTION OF SUPERSONIC PROPELLER NOISE

F. Farassat
Aeroacoustics Branch
Extension 2645

Research Objective - The prediction of the noise of supersonic propellers is an important subject of research because of the current concern about possible community annoyance by future ATP driven aircraft. A reliable prediction scheme can help in the design of both the propeller and the fuselage to reduce noise in the exterior and interior of the aircraft. The objective of this research is to develop a new noise prediction code which will speed up the computation time without deteriorating the accuracy of an existing sophisticated code.

Approach - Starting with the governing acoustic equation (the Ffowcs Williams-Hawkings equation), the sources were assumed to lie on mean camber surface of the blade. Using the method of a recent publication for full surface result, (AIAA 84-0250) a simple expression for the loading and thickness noise of rotating blades was derived. This expression involves several surface integrals over the mean surface and line integrals over the edge of the planform. This formulation is valid in the near and far fields and blades in supersonic motion.

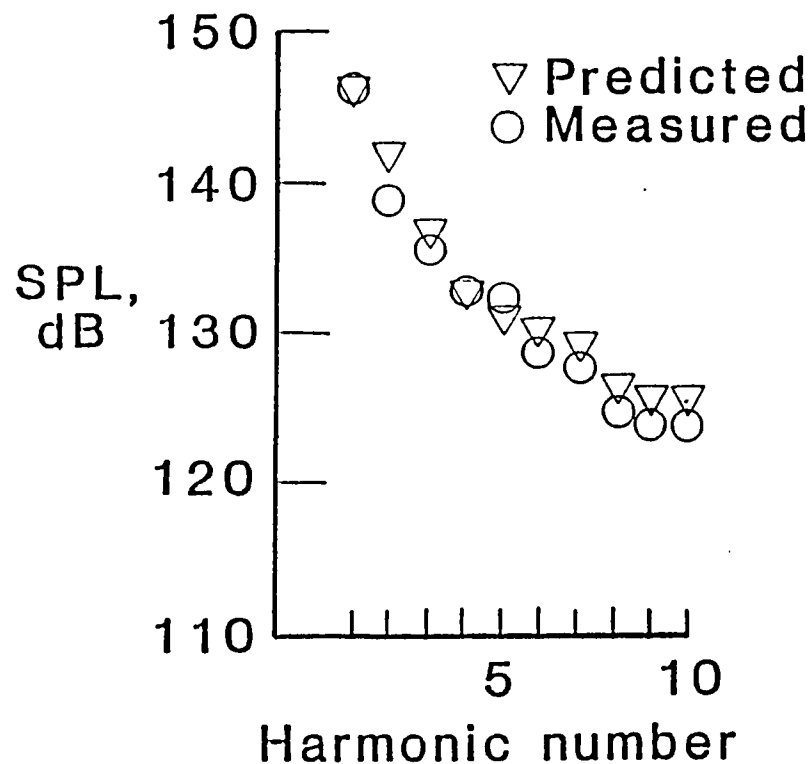
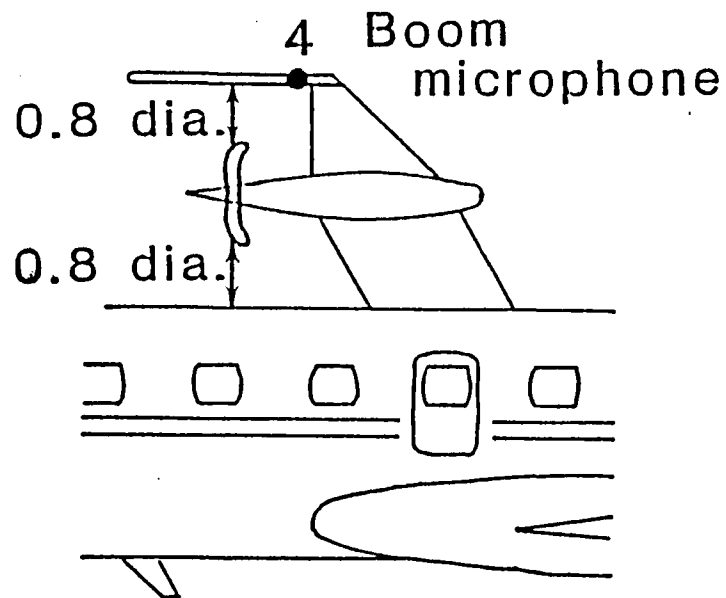
Accomplishment Description - A new computer code based on the present acoustic formulation was developed for prediction of the noise of high speed propellers. Comparison with results from a full surface code has shown an improvement in execution time by approximately a factor of two. The results from the new code also compare well with those from the full surface code. The new code is also less sensitive to mesh size of integration for numerical evaluation of integrals in the acoustic formulation. The accompanying figure shows a comparison of the measured and computed acoustic spectra of an eight-bladed prop-fan (SR-3). The measured data corresponds to boom microphone position 4 from the Jetstar operating at design condition at 30,000 ft. The level of each harmonic of the theoretical spectrum is increased by 4 dB to account for scattering by the boom itself, assuming a rigid surface without the boundary layer. It is observed that the agreement between the theoretical and measured data is good. Similar results were observed in other cases.

Future Plans - The data from a number of runs from the Jetstar prop-fan (8 SR-3 blades) test are being analyzed for comparison with prediction. The aerodynamic input to the acoustic program will be supplied from a three dimensional Euler code. Color graphics of sound intensity pattern of SR-3 design will also be obtained.

Figure 8(b).

PREDICTED PROPELLER NOISE USING MEAN SURFACE CODE

SR-3 PROPELLER, $M = 0.8$, $h = 30,000$ ft



ACOUSTIC PRESSURE SPECTRA

Figure 8(b).- Concluded.

AERODYNAMIC COMPUTATION USING ACOUSTIC FORMULATION

K. S. Brentner
Aeroacoustics Branch
Extension 4308

Research Objective - The recently derived integral formulation for aerodynamic analysis based on an acoustic formula in the time domain, by Lyle N. Long, is solved numerically using Galerkin's method. The particular advantage of Galerkin's methods is that it provides a continuous pressure distribution function on the blade surface, which is very useful for propeller and rotor noise prediction.

55 Approach - The solution to Long's integral equation has been divided into thickness and loading contributions. The singular integral equation is solved numerically using a linear combination of basis functions to approximate the pressure distribution on the surface. A unique combination of the basis functions is found by setting the residuals orthogonal to the basis functions. If a complete set of basis functions is used, this procedure is exact. For numerical integration, the blade surface is divided into panels and Gauss-Legendre quadrature is used over each panel. The singularity is handled by evaluating the integrals over a small region analytically. Compressibility is fully taken into account and the formulation is entirely three-dimensional.

Accomplishment Description - The thickness contribution has been tested and the results are encouraging. The test case presented in the attached figure is a propeller with constant chord NACA 0012 airfoil section twisted so that each section is at zero degrees angle of attack with forward velocity, thereby eliminating the loading contribution. In the figure, the chordwise pressure distribution for the three-dimensional flow is compared to two-dimensional, incompressible theory. Note that the coefficient of pressure C_p is plotted against the non-dimensional chord location x/c at a helical Mach number of 0.39. The figure shows a generally lower pressure for the present method as would be expected due to the three-dimensional relief effect. The difference at the trailing edge is due to the choice of basis functions in the present method and is more realistic than the incompressible theory. It should be mentioned, however, that Long neglected some higher order terms, normally dropped in acoustics, which seem to be significant in aerodynamics.

Future Plans - In future work, the thickness contribution to the pressure distribution will be enhanced with the higher order terms included in the solution, and the loading contribution to the pressure distribution will be also included.

Figure 8(c).

COMPUTED PRESSURE DISTRIBUTION USING
ACOUSTIC FORMULATION

85% PROPELLER RADIUS

FORWARD $M = .29$

HELICAL TIP $M = .45$

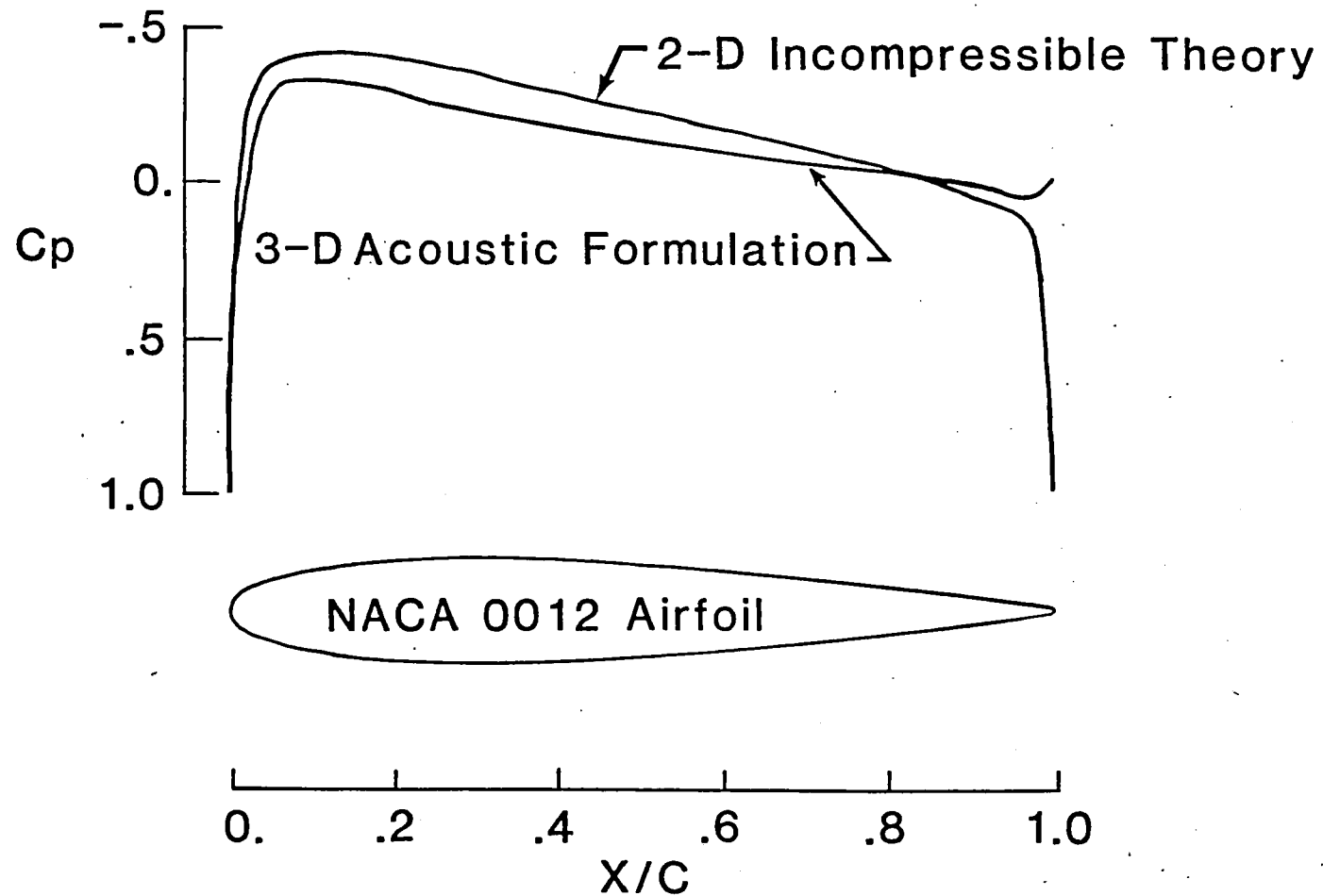


Figure 8(c).- Concluded.

HELICOPTER DISCRETE FREQUENCY NOISE PREDICTION

Kenneth S. Brentner
Aeroacoustics Branch
Ext. 2645

Research Objective - The objective of this research is to advance the current capability of helicopter rotor noise prediction using a combined theoretical/computational approach. The most advanced acoustic formulation is coupled with up-to-date development in aerodynamic and dynamic computations to predict helicopter rotor noise.

Approach - A recent acoustic theory developed in-house by Farassat is used for noise calculation. The theory is formulated in the time domain for efficient computation and is ideally suited for both farfield and nearfield noise prediction of subsonic rotors. However, its prediction ability depends on the aerodynamic load inputs to the acoustic code. Therefore, rotor aerodynamic and dynamic codes of various sophistication have been obtained from Army Aerostructures Directorate and NASA Ames. These codes are used to compute the blade motion and blade loading required as input to the acoustic theory. The predicted rotor noise is compared to experimental data for a quarter scale UH-1 model rotor obtained by Army Aerostructures Directorate in Langley's 4- by 7-Meter Wind Tunnel.

57 Accomplishment - Code development incorporating Farassat's new acoustic theory is completed. The developed code has been successfully verified for coupling with aerodynamic codes. A user's guide for the acoustic code is being prepared. A rotorcraft flight simulation code, used extensively by Army Aerostructures Directorate, C81, was used to compute the blade motion and lift distribution for the quarter scale UH-1 rotor with standard rectangular blade planform. A typical prediction from the coupled acoustic/aerodynamic/dynamic code is compared in the attached figure for a blade tip Mach number, M_t , of 0.857 where the noise radiation is dominated by blade thickness. The general features of the acoustic time history are well predicted as are the levels of the first 30 blade harmonics. The ability accurately predict noise at higher blade harmonics is considered an important accomplishment of the present coupled code. The codes are now being applied to predict rotor noise for cases where radiation is dominated by blade loading. The acoustic code developed in this research has been requested by and sent to Bell Helicopter, Sikorsky, Boeing Vertol and Army Structures Directorate.

Future - Using the present acoustic code, predictions will be made to support the joint NASA/DFVLR main rotor noise experiment to be performed in the German-Dutch Wind Tunnel in the spring of 1986. A more sophisticated aerodynamic/dynamic code developed at NASA Ames, CAMRAD (Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics), is now being investigated for improving blade motion and load distribution. In the future, an advanced 3-D transonic code developed at NASA Ames, TFAR (Transonic Flow Analysis for Rotors), will be used to compute the unsteady 3-D blade surface pressure distribution required for blade-vortex interaction noise calculation. Each of the above codes will be coupled to the present acoustic code for noise prediction and results compared with available experimental data.

HELICOPTER DISCRETE FREQUENCY NOISE PREDICTION

Model UH-1 Rotor, Quarter Scale, $M_t = 0.857$

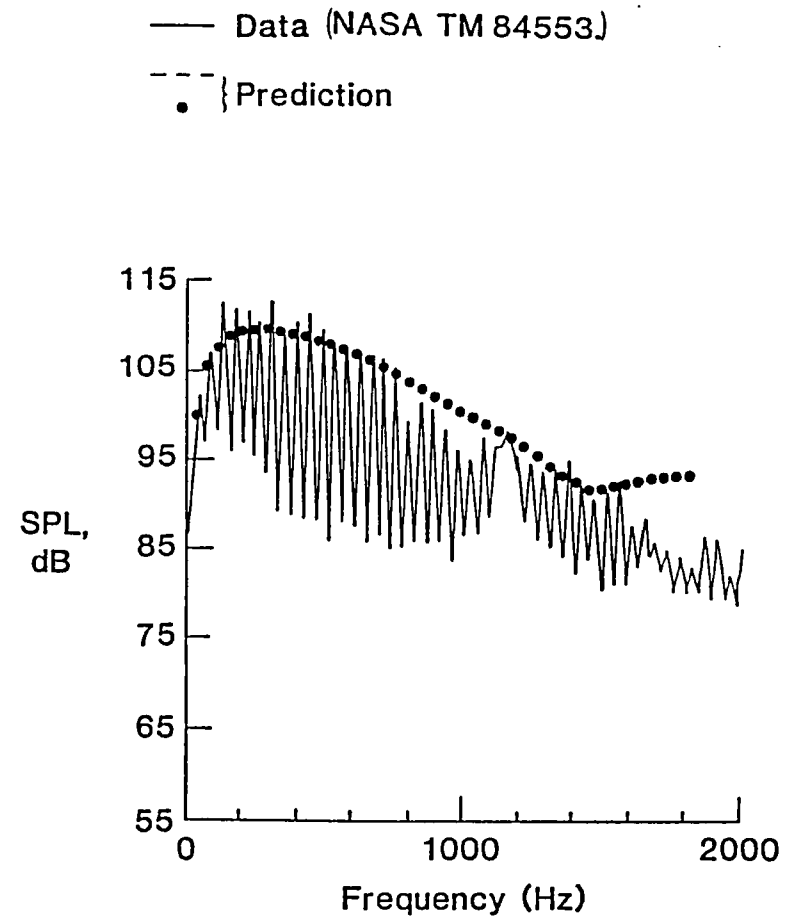
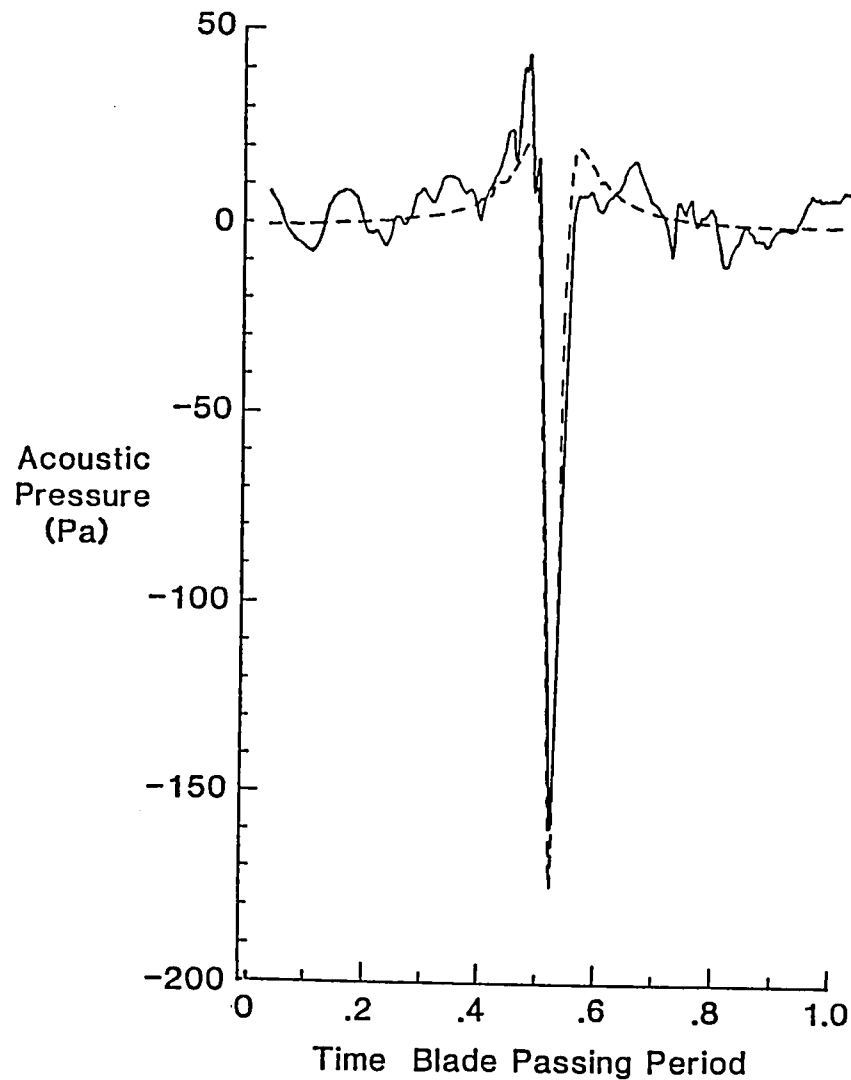


Figure 8(d).- Concluded.

VORTEX DISTORTION DURING BLADE/VORTEX INTERACTION

J. C. Hardin
Aeroacoustics Branch
Extension 2645

Research Objective - One of the major sources of noise radiation from helicopters is due to the interaction of the rotor blades with tip vortices shed by the previous blades. In order to understand and control this phenomenon for noise reduction, the dynamics of the interaction process must be carefully examined. Thus, an extensive in-house program to analytically, numerically and experimentally document the fluid dynamics and aeroacoustics of blade/vortex interaction has been developed.

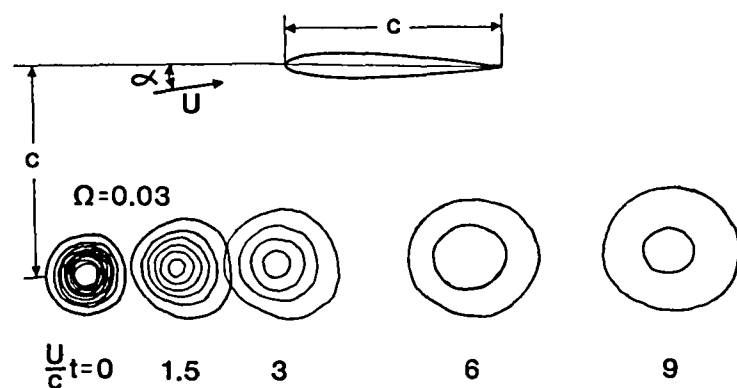
Approach - Previous analyses of this problem have either employed a vortex singularity, where the structure of the vortex is totally obscured, or, if a distributed vortex has been utilized, the distribution has been taken as fixed, which does not allow for any distortion of the vortex during the interaction. In an attempt to remove this restriction, a first principles computational fluid dynamics approach to the two-dimensional problem has been developed. In this analysis, a distributed vortex is input upstream of a lifting airfoil and the subsequent convection and viscous encounter of the vortex followed by numerical solution of the Navier-Stokes equations in the stream function/vorticity formulation.

Accomplishment Description - One of the most interesting results of this study is the distortion and/or apparent diffusion of the vortex during the encounter. The figure on the left is a montage showing the position and vorticity contours of the distributed vortex at a succession of non-dimensional times as it passes the airfoil. Note that the vortex which is initially circular is significantly distorted due to its interaction with the velocity gradients induced by the lifting airfoil ($\alpha=5^\circ$). The circulation of the vortex has the same magnitude as the lift on the airfoil and the vortex is initially one chord length below. The outermost contour shown in the figure corresponds to the smallest value of non-dimensional vorticity (Ω), 0.03. If the outermost contour is represented by a circle, the figure on the right compares the non-dimensional radius of that circle with that predicted by the exact solution of the Navier-Stokes equations for a viscous vortex in free space having the same radius at the initial time. Note that the computational solution for the blade/vortex interaction displays a much higher initial apparent diffusion rate than would be expected for a vortex in free space. Such apparent diffusion is a real effect produced by the shearing of the vortex by the airfoil velocity gradients. This effective destruction of a distributed vortex by a close encounter has important implications for blade/vortex interaction noise and has also been observed in in-house experiments.

Future Plans - The present study is part of an ongoing effort to understand and predict noise generation by blade vortex interaction. Future plans include increasing the Reynolds number and computational speed of the solutions.

VORTEX DISTORTION BY BLADE/VORTEX INTERACTION

VORTICITY CONTOURS DURING ENCOUNTER



APPARENT DIFFUSION DURING ENCOUNTER

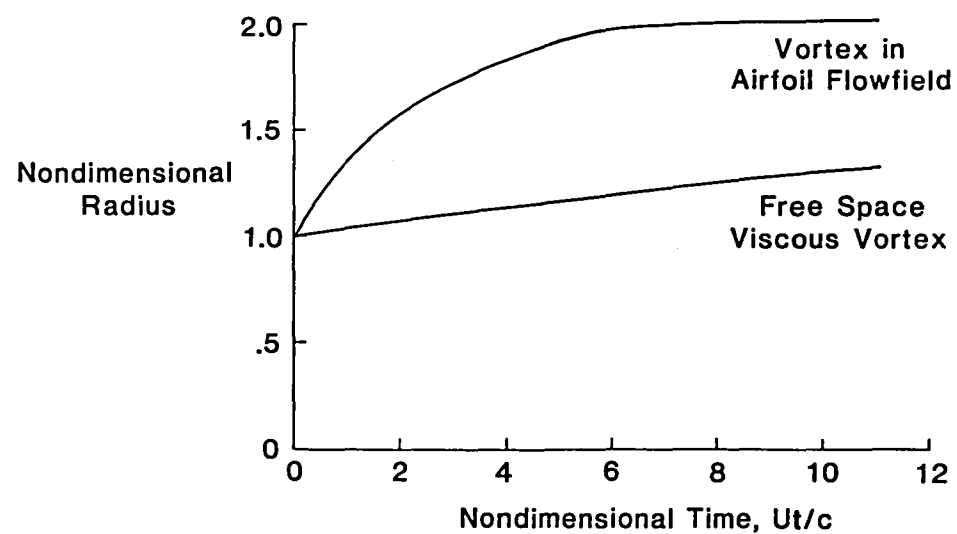


Figure 8(e).- Concluded.

VORTEX STUDIES RELATING TO BOUNDARY LAYER TURBULENCE AND NOISE

J. L. Adelman and J. C. Hardin
Aeroacoustics Branch
Extension 2645

Research Objective - Boundary layer turbulence is of importance in aeroacoustics because it increases the noise radiation into the interior of the body. The present research is an attempt to obtain a better understanding of boundary layer turbulence in the hope that methods for controlling its noise radiation might be devised.

Approach - Turbulent boundary layers are comprised of vorticity whose magnitude and direction is dictated by the flow direction and surface geometry. As a simple model of a turbulent boundary layer, this study considers the two-dimensional problem of an array of N like-sign, rectilinear point vortices above an infinite flat plane. For such an array, the method of images may be employed to reduce the problem to that of $2N$ vortices in free space restricted by $2N$ symmetry relations. This system is Hamiltonian and, thus, certain invariants of the motion are known. Further, the equations governing the vortices are readily obtained and can be integrated numerically to determine the vortex trajectories. From a knowledge of the time-dependent vortex motion, the resulting noise radiation may be computed by standard aeroacoustic techniques.

Accomplishment Description - This model has been studied both analytically and numerically for many different initial vortex configurations. Two interesting cases for $N=2$ are shown on the accompanying montage. The upper left hand corner displays the trajectories of two identical vortices which oscillate around one another as they convect with a velocity dependent upon their distance from the plane. The noise radiation to a fixed observer location in this oscillating case is also shown in the lower left. The modulation of the noise signal is due to the directivity of the noise source as it moves with respect to the observer. The upper right hand corner similarly shows trajectories of two identical vortices. In this non-oscillating case, the faster convection of the vortex closer to the wall, due to the influence of its image, causes there to be very little interaction between the two vortices and, thus, very little noise generation as shown on the lower right. A criterion,

$$(h^2 - y_0^2)(x_0^2 + h^2) > h(x_0^2 + y_0^2)$$

where x_0 and y_0 are the initial separations of the two vortices in the x and y directions and h is twice the initial average height of the vortices above the infinite plane, for the occurrence of the oscillating case has been derived. The difference in these two cases is similar to the difference between laminar and turbulent boundary layers.

Figure 8(f).

VORTEX STUDIES RELATING TO BOUNDARY LAYER TURBULENCE AND NOISE

CONTINUED

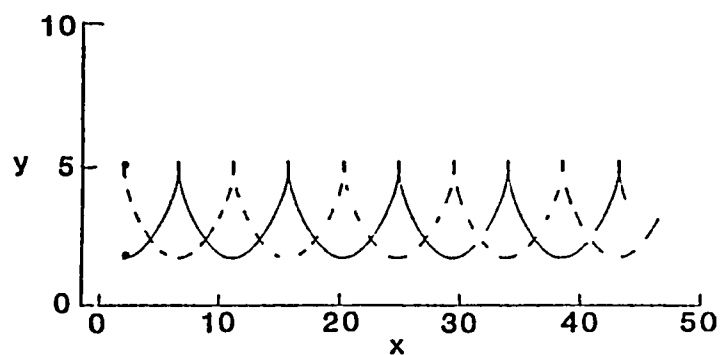
Future Plans

The analysis has been extended to non-identical vortices and by the addition of a shear flow. For $N > 3$, the interesting phenomenon of chaotic solutions is present. These results indicate that by controlling the spacing of vortices in a boundary layer, a reduction in noise production might result. This possibility will be the subject of future analytical work.

Figure 8(f).- Continued.

VORTEX MOTION AND NOISE GENERATION

Oscillating Case



Non-Oscillating Case

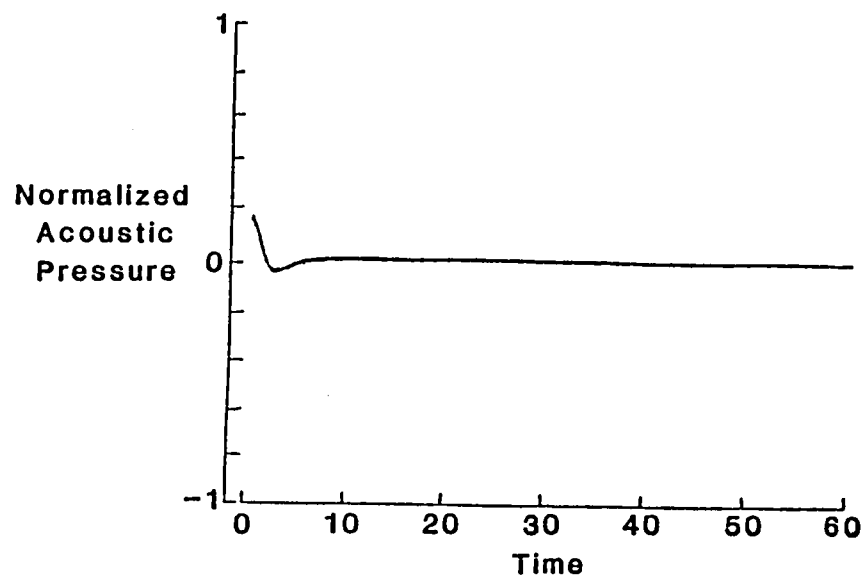
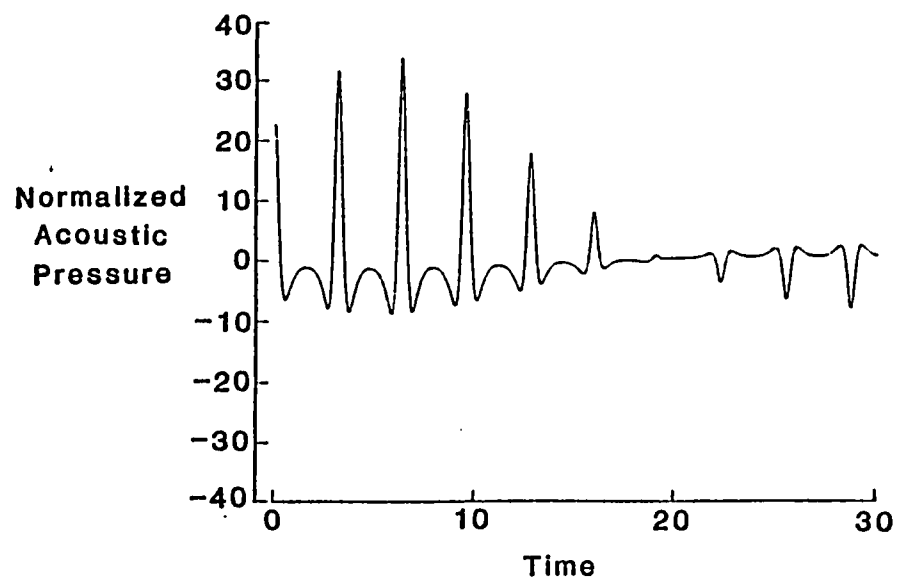
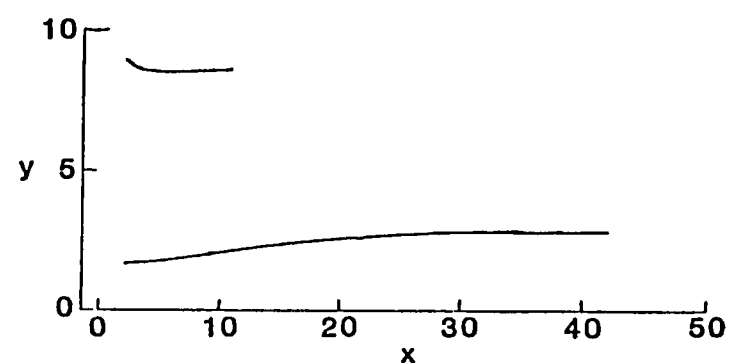


Figure 8(f).- Concluded.

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SIMULATED FLIGHT EFFECTS ON SUPERSONIC JET NOISE

T. D. Norum and J. G. Shearin
Aeroacoustics Branch
Extension 2645

Research Objective - The noise emitted by a supersonic jet is enhanced by the existence of shocks in the jet plume. Although there is an abundance of data from static supersonic jets, there is little information on the effects of flight on shock associated noise. This study examines the simultaneous effects on the mean plume structure and radiated noise due to simulated forward motion.

Approach - A one inch diameter convergent nozzle was operated at supersonic conditions inside a low speed flow issuing from an 18 inch concentric nozzle. Measurements of far field acoustic pressure and surveys of the plume static and stagnation pressures were obtained for fully expanded jet Mach numbers between 1 and 2 and simulated flight speeds to 175 fps.

Accomplishment Description - The difference between the noise emitted from the underexpanded jet statically and in simulated flight can be seen in the spectra presented for angles from the inlet axis of 40° to 150° . The jet mixing noise, typified by the spectra at the downstream angles, decreases in flight in the same manner as for a subsonic jet. At the nozzle pressure ratio of 2.7, the main effect of flight on the shock associated noise is to reduce the frequency of the screech tones, consistent with the measured increase of downstream shock cell lengths and the increased period of the feedback cycle. A markedly different effect is obtained at the pressure ratio of 4.5, where both the screech and the broadband shock associated noise show large changes with flight. The plume measurements show a corresponding change in the structure of the downstream shock cells, indicating a strong coupling between the jet's acoustic mode and its rate of spreading that can change with flight speed.

Future Plans - Attainment of up to 4 times the flight speed appears to be attainable with little or no change to the ANRL facility. This will provide a more reliable quantitative assessment of flight effects on shock associated noise as well as define the extensiveness of the large scale changes due to mode shifts.

Figure 9(a).

SIMULATED FLIGHT EFFECTS ON SUPERSONIC JET NOISE

99

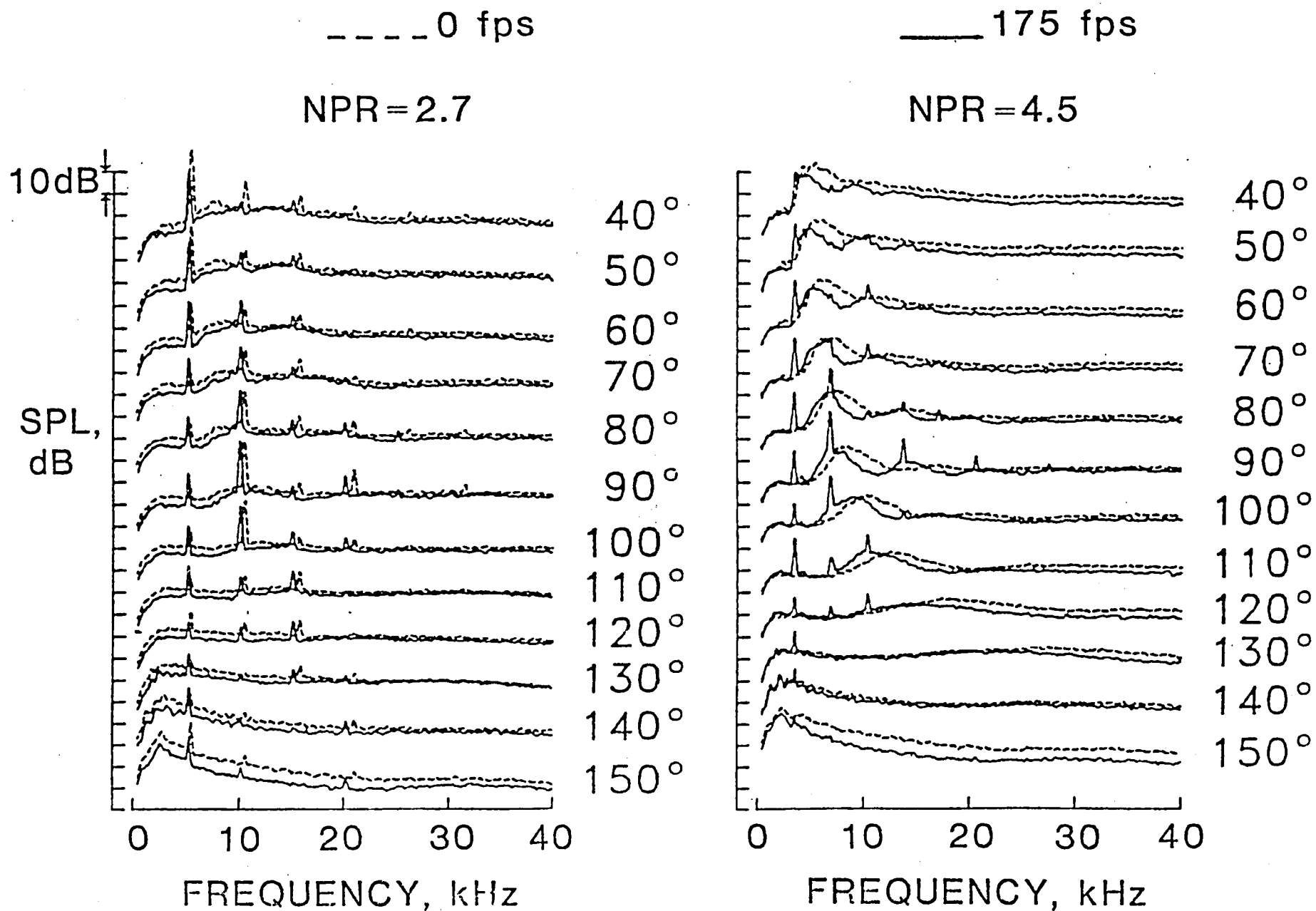


Figure 9(a).- Concluded.

ACOUSTIC LOADING FROM DUAL SUPERSONIC JETS

T. D. Norum and J. G. Shearin
Aeroacoustics Branch
Extension 2645

Research Objective - Structural failure of components of the exhaust nozzles of the B1 bomber and the F15 fighter aircraft have led to an increase in boattail drag and a subsequent loss of performance. One possible cause of this phenomenon is acoustic loading due to the supersonic jet exhaust. This study examines the acoustic near field generated by single and dual nozzle configurations to determine if closely spaced dual nozzles generate significantly higher acoustic loading than that encountered with a single nozzle.

Approach - Dual nozzles constructed from five-eighths inch pipe were tested in the ANRL simulated flight facility as shown in the photograph. The spacing between nozzle centerlines was scaled from the B1/F15 aircraft. A microphone (not shown) was attached to the nozzles' interfairing just upstream of the jet exit. Single nozzle results were obtained by blocking the flow in one of the pipes.

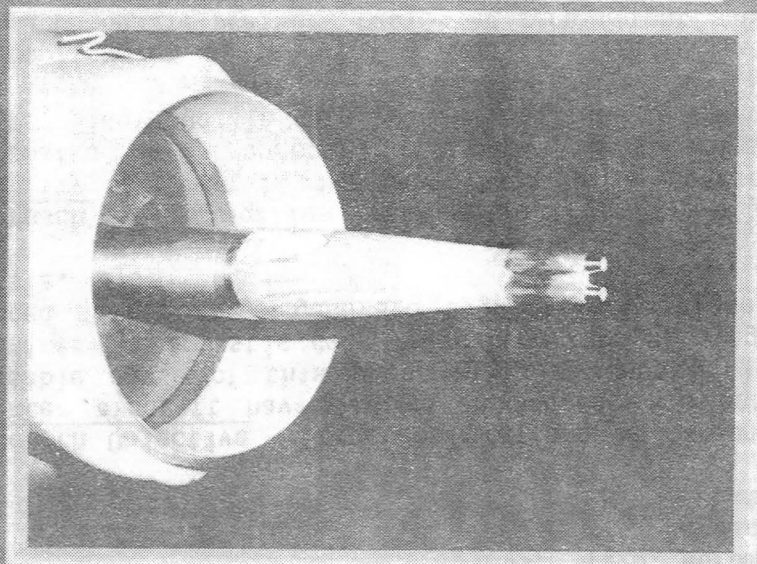
Accomplishment Description - Acoustic spectra were obtained for both nozzle configurations over a wide range of nozzle pressure ratios at zero flight speed. The amplitudes of the screech tones generated by the jets were determined from these spectra and their variations with the jets' fully expanded Mach number are shown in the figure. The five commonly obtained stages of screech (each identified by a typical frequency variation and labeled as the A_1 , A_2 , B, C, and D modes) were found to exist for both configurations. Results shown in the figure are very similar for all but the B stage (known to be the most unstable mode). The coupling between the two jets has a strong effect on the B mode, yielding an increase in screech amplitude over the single jet of more than 20 dB near a Mach number of 1.5. The measured amplitude exceeds 150 dB over a wide range of operating conditions, indicating that high dynamic pressures (exceeding 0.1 psi) can exist upstream of the exit plane of the dual nozzles.

Future Plans - The aeroacoustic coupling leading to the strong reinforcement of the stage B screech for a dual nozzle configuration will be investigated by optical methods. Elimination of the coupling through spacing or staggering of the nozzles as well as the effects of flight will also be examined.

Figure 9(b).

ACOUSTIC LOADING FROM DUAL SUPERSONIC JETS

F15/B1 DUAL NOZZLE CONFIGURATION



AMPLITUDES OF SCREECH TONES

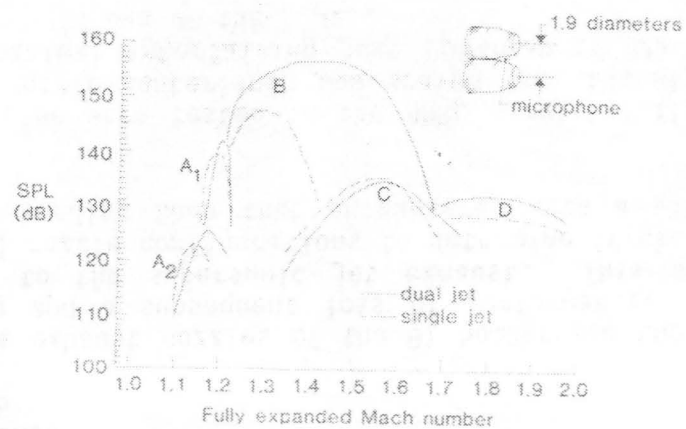


Figure 9(b).- Concluded.

LOAD REDUCTION ASSOCIATED WITH TWIN SUPERSONIC PLUME RESONANCE

John M. Seiner
Aeroacoustics Branch
Extension 3094

Research Objective - Closely spaced supersonic engines, i.e., those with inter-nozzle distances less than one nozzle diameter, are commonly utilized by the aircraft designer to improve performance. This engine configuration is incorporated on the F-15, F-18, and the B1-B aircraft. Each of these aircraft have experienced fatigue failures in the inter-nozzle region. Previous investigations into this problem have focused on flow induced separation due to the complex nozzle fairing geometry; however, these studies have been unsuccessful in explaining the observed structure failures. Thus, it was conjectured that these fatigue failures might be caused by strong coupling between the natural jet instabilities of each plume that could lead to enormous growth rates and excessive near field pressure levels.

Approach - In order to investigate this possibility, a 1/40th scale model was constructed as shown in the upper left figure. A sensor was placed in the inter-nozzle region to obtain fluctuating dynamic pressures. This sensor also served as a reference to obtain phase averaged Schlieren records. The optical records were used to identify the spatial plume structure associated with the large amplitude pressure fluctuations. In addition, several passive methods of suppression were investigated to eliminate possible plume coupling by altering the stability characteristics of the individual plumes.

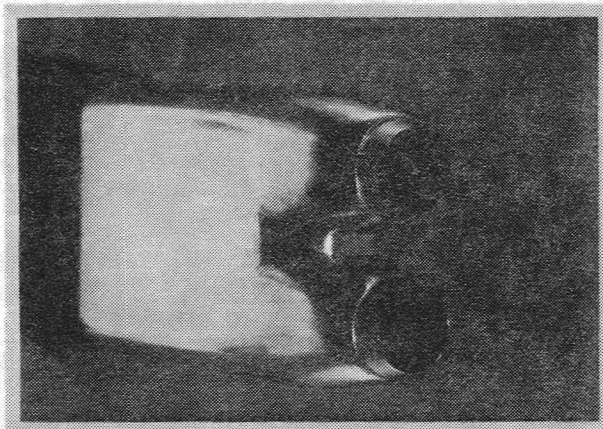
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Accomplishment Description - The pressure data in the upper right figure show that pressure levels for many plume Mach numbers M_j are in a range where possible sonic fatigue failures can be anticipated. Also shown in this figure is the satisfactory reduction obtained with one suppression method where thrust loss is expected to be minimal. The lower left phase averaged Schlieren shows that each plume is dominated by helical instabilities (B-mode type), that they are coupled together as they evolve downstream, and that a strong pressure field exists between each plume. This pressure field propagates toward the inter-nozzle region. Intense acoustic wavefronts can also be observed propagating upstream on the outside of each nozzle. The phase averaged Schlieren on the lower right shows that after suppression the wave structure between each plume is no longer equal, the plumes are uncoupled, and the intense inter and outer pressure waves have been practically eliminated.

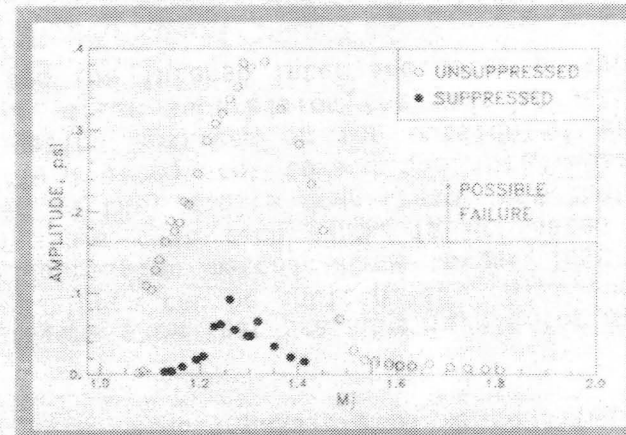
Future Plans - To establish proof of concept for twin plume resonance plans are currently being drawn to conduct a full scale flight test program at Dryden using the F-15. In addition a 1/24th scale model, built by McDonnell Douglas, will be studied at Langley. Both acoustic and performance testing will be conducted, and the studies will include examination of the twin 2-D nozzle configuration. This latter configuration is the expected design for the ATF.

Figure 9(c).

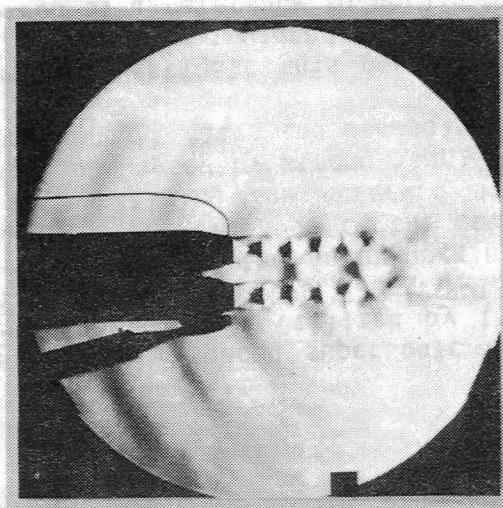
LOAD REDUCTION ASSOCIATED WITH TWIN SUPERSONIC PLUMES



Model (1/40 Scale)

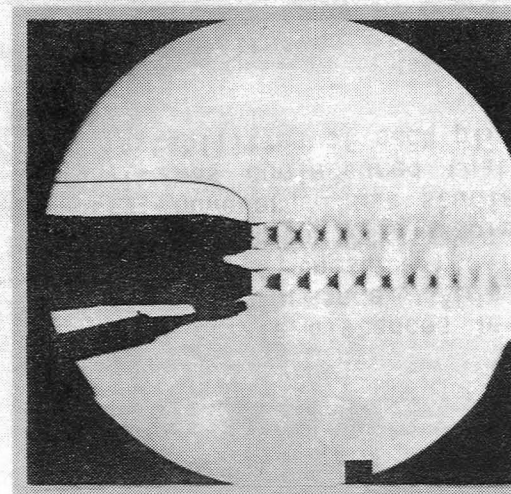


Magnitude of Load Reduction



Resonance Unsuppressed

$M_j=1.3$



Resonance Suppressed

$M_j=1.3$

Figure 9(c).- Concluded.

ACOUSTIC PROPERTIES OF A NON-AXISYMMETRIC SUPERSONIC NOZZLE

J. M. Seiner
Aeroacoustics Branch
Extension 3094

Research Objective - Based on performance studies by Langley's Propulsion Integration Branch it has been previously shown that the 2-D C-D (convergent-divergent) supersonic exhaust nozzle substantially reduces boattail drag when integrated to the fuselage of an advanced tactical fighter aircraft. In similar studies it was also shown that cutting back nozzle sidewalls would not result in any significant performance loss, and at the same time would enhance vectoring capability, lower cooling requirements and reduce nozzle gross weight. Of concern however, was consideration as to whether an increase in acoustic load might be introduced due to nozzle sidewall cut-back that would require additional vehicle gross weight to satisfy sonic fatigue criteria.

Approach - Recently the far field acoustic properties of a candidate 2-D C-D supersonic nozzle was examined to determine if cutting back nozzle sidewalls would lead to any important change in acoustic emissions. The upper sketches illustrate nozzles with full and cut-back sidewalls respectively. With full sidewalls the nozzle's design exhaust Mach number is 1.66, and the throat aspect ratio is 2/1.

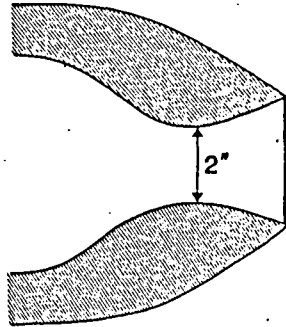
Accomplishment Description - Preliminary results from this study are shown in the lower figure. The narrowband acoustic power spectral density (PSD) show that when the sidewalls are cut-back a significant increase in acoustic energy can be detected. The increase in energy is represented by the appearance of high amplitude tones, which can be associated with either jet screech or periodic flow separation from the nozzle side walls. This data refers to operation at the nozzle's design point, and it is to be noted that there exists, for even the full sidewall case, significant shock noise radiation.

Future Plans - Future research on this concept will focus on the physical nature of this increase in acoustic energy by studying the associated time dependent aerodynamic source. In this way a solution may be obtained to eliminate this noise source component and thereby prevent structural design modifications that would be required in this case to prevent sonic fatigue.

Figure 9(d).

EFFECT OF PARTIAL SIDEWALLS ON ACOUSTIC EMISSIONS FROM LOW ASPECT RATIO 2D-CD NOZZLES

NOZZLE WITH FULL SIDEWALLS



NOZZLE WITH 75% CUT-BACK SIDEWALLS

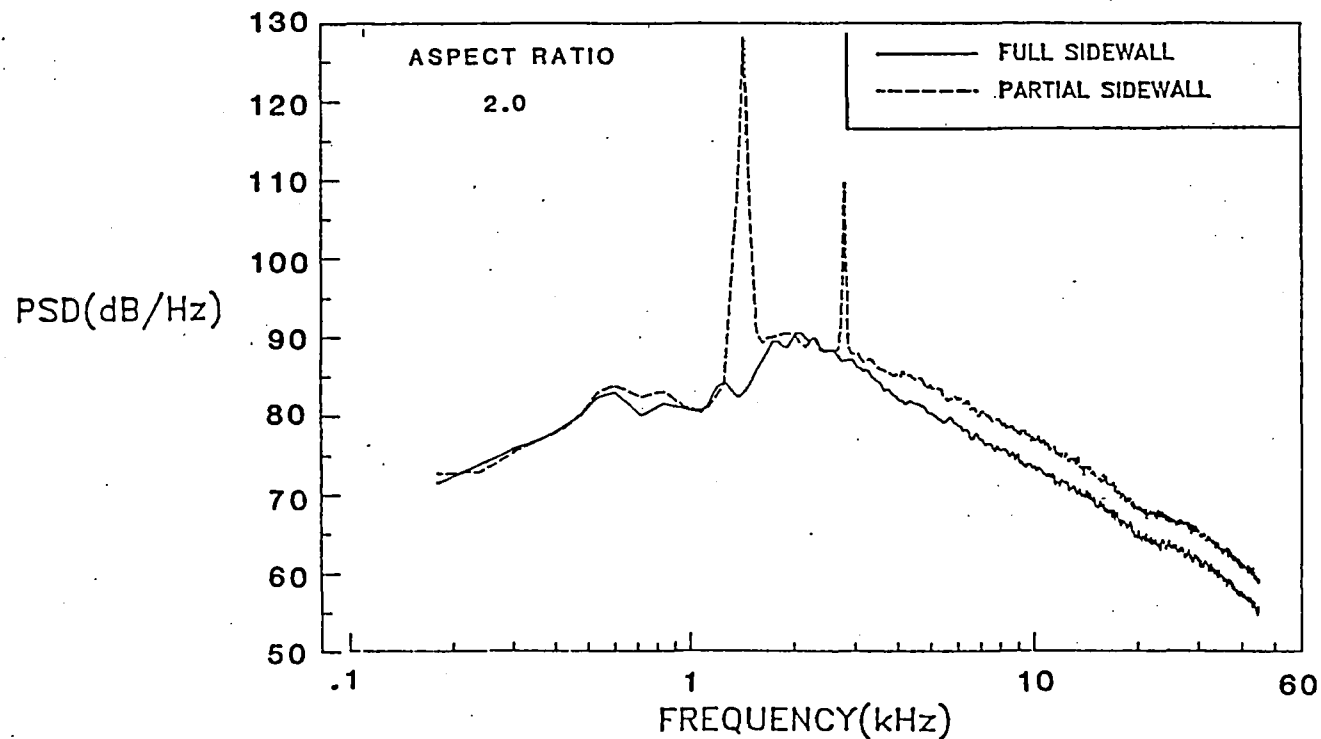
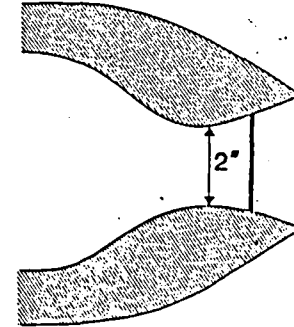


Figure 9(d).- Concluded.

AEROACOUSTICS BRANCH

FY 86 PLANS

Supersonic Jet Noise

- o Complete measurement of the aerodynamics and acoustics of dual stream jet exhaust resonance relevant to B1 and B15 sonic fatigue problems.
- o Complete interim prediction of nearfield acoustics of 2D-CD supersonic jet nozzles.

Rotorcraft Aeroacoustics

- o Complete model rotor broadband and BVI noise measurement in DNW.
- o Complete 2-D BVI unsteady flow measurement.
- o Complete main rotor/tail rotor acoustic and aerodynamic measurements.

Computational Aeroacoustics

- o Complete Euler code BVI aeroacoustics computation using distributed vortex.
- o Validate supersonic propeller noise prediction code using LeRC loads and GE data.
- o Integrate acoustic and aerodynamic prediction methods and compare with data.
- o Develop accurate noise prediction model for counter rotation propellers.

AEROACOUSTICS BRANCH

FY 86 Plans: Narrative

Supersonic Jet Noise:

A focused theoretical effort is directed toward understanding the large scale wave motion of jet plumes such that the condition of occurrence, dominant frequency, and amplitude of screech tones can be predicted accurately. Static and flight tests of twin plume resonance effect, which has been observed in model scaled twin supersonic jets, will be conducted with the assistance of Dryden Flight Center using their F-15 aircraft. The results will be highly significant for applications to structural fatigue and the optimization of engine installation aerodynamics. Furthermore, advanced aeroacoustic research will be pursued in the Langley Jet Noise Laboratory to investigate effects of high temperature and Mach numbers.

Rotorcraft Aeroacoustics:

The MR/TR interaction noise Phase III experiment will be conducted in the Langley 4- by 7-Meter Wind Tunnel during the first quarter of FY 86. Immediately following the MR/TR experiment, final detailed preparation will begin for the April entry of the DNW broadband and BVI noise experiment in The Netherlands. The DNW project is jointly sponsored by the FAA, Army Aerostructures Directorate, and NASA. In addition, substantial cooperative support for this experiment is provided by DFVLR and DNW through an international agreement with DFVLR. Inhouse efforts of two-dimensional BVI experiment will continue with advanced instrumentation for optical and surface pressure measurements. Prediction methodology and an accompanying data base will be provided to the ROTONET staff for final programming of the rotor broadband noise prediction module.

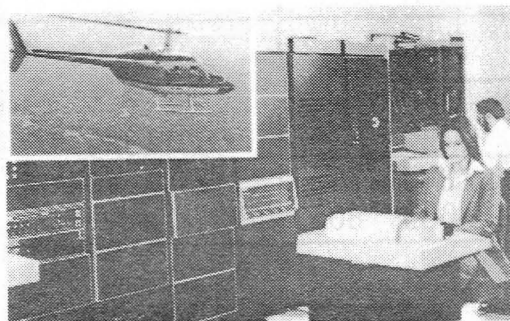
Computational Aeroacoustics:

Focused effort for integrating computational methods of acoustics and aerodynamics (CFD) is underway in both ATP and rotor noise areas. The initial interdisciplinary approach in FY 85 has already led to improved understanding of aerodynamic pressure prediction requirements in order to obtain accurate acoustic predictions. CFD prediction of blade/vortex interaction in the inviscid and high Reynolds number regime will continue in FY 86. Such results will be quantitatively compared to experimental data.

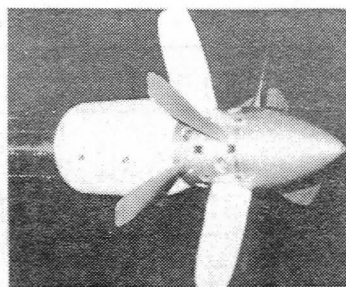
Following major developments of ATP noise prediction technology accomplished last year, efforts will be focused upon the collaborative effort with LeRC, Hamilton Standard, and GE to improve full surface and mean surface noise prediction codes which are based on Formulation 3 of the Farassat code, its integration with aerodynamic codes, and to compare both aerodynamic predictions and acoustic predictions with available data. Accurate noise prediction code for counter rotating advanced propellers will be developed in FY 86.

Figure 11.

APPLIED ACOUSTICS



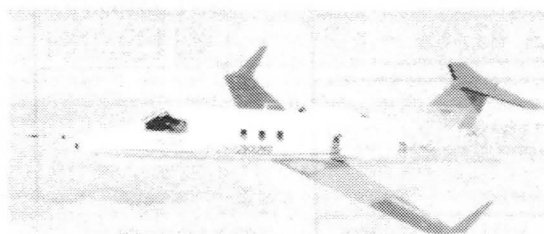
Rotonet



Propeller noise



NASA/AHS program



Laminar flow acoustics



Propagation

Figure 12.

APPLIED ACOUSTICS

5-YEAR PLAN

MAJOR THRUSTS	FY 85	FY 86	FY 87	FY 88	FY 89	EXPECTED RESULTS
HELICOPTER ACOUSTICS	ROTONET-1ST FULL SYS. PRED.- QUASI-STEADY		BVI & MAIN ROTOR & TAIL ROTOR PREDICTION			FAR FIELD NOISE PREDICTION CAPBILITY
	BROADBAND NOISE PREDICTION		500-D FLIGHT AND ANALYSIS		APACHE FLT TEST W/LOADS	INCREASED NOISE REDUCTION CAPABILITY
	AHS PROGRAM: IMPROVED ANALYTICAL MODELS; CRITICAL TUNNEL, TOWER & FLIGHT TESTS					
PROPELLER ACOUSTICS	QFF- SR/CR EXP. ANAL.		LOW NOISE MODEL(S) TEST IN TRANSONIC WIND TUNNEL			VALIDATED ADVANCED HIGH - SPEED PROPELLER PREDICTION
	SUPERSONIC TIP HIGH HIGH POWER TUNNEL TEST & ANALYSIS					
	PREDICTION/THEORY EVALUATIONS AND REFINEMENT					
BOUNDARY LAYER ACOUSTICS	COOP AERO PROGRAMS 757/LEAR/QV-1B					PREDICTION MODEL WITH NOISE INTER-ACTING WITH BOUNDARY LAYER
	BOUNDARY LAYER INTERACTION ACOUSTIC THEORY					
	CRITICAL LAB EXPERIMENTS					
ATMOSPHERIC PROPAGATION	HIGH WIND & THERMAL/ TESTS/THEORY			ADV. MODEL DEVEL.		PREDICTION MODEL INCLUD. LONG DIST SHALLOW ANGLES LOW FREQ; HIGH WINDS FOR DETECT. AND CERTIFICATION
	REALISTIC TOPOGRAPHY STUDIES					
	SCALE MODEL STUDIES		LOW FREQ. PROPAG.			

Figure 13.

EFFECTS OF NOISE ON LAMINAR FLOW

James A. Schoenster
Applied Acoustics Branch
Extension 4305

Research Objective - To determine the near-field noise environment of aircraft and the effect of this noise field on laminar flow surfaces.

Approach - The initial effort in this program is to join on-going activities of the Aeronautics groups involved in laminar flow studies. Three existing programs include a program to modify a section of the wing on a Boeing 757 with a "boot" which will provide laminar flow over a 3- to 4-foot chord length; a flight test of a Lear 28/29 jet which has natural laminar flow over a significant area of the wing; and a flight test of three different engine nacelles on the OV-1 to evaluate the ability to design laminar flow nacelles. Acoustic measurements will be obtained on all three of these aircraft to provide data on the different aircraft environments, the effect noise has on laminar flow, and the ability to obtain reliable noise measurements on the aircraft during flight. These data will be evaluated along with other existing work to select areas of research needed to provide a basis for determining the near-field noise environment and the effects of these noise fields on laminar flow surfaces.

Future Plans - Based on the results of the preliminary studies, a balanced program of analytical and experimental studies will be initiated to provide a prediction method of noise effects on laminar flow for aircraft design. Both in-house and contractual efforts will be required to cover the aeronautical and acoustical research work necessary to conduct this program.

Figure 14(a).

PLANNED ACOUSTIC MEASUREMENTS

ON LAMINAR FLOW SURFACES IN FLIGHT



"Booted" Laminar Flow Wing



Natural Laminar Flow Wing



Laminar Flow Nacelle

- **Aircraft Acoustic Environment**
- **Noise Effects On Laminar Flow**
- **Boundary Layer Effect On Noise Measurements**

Figure 14(a).- Concluded.

FLUCTUATING LOADS ON A LAMINAR-FLOW GLOVED-WING SECTION OF A 757 IN FLIGHT

James A. Schoenster
Applied Acoustics Branch
Extension 4305

Research Objective - The application of laminar flow concepts for large subsonic aircraft has been determined to offer significant savings in fuel usage. While much work has been conducted in developing these concepts, concern about the practicality of laminar flow still exists. One of the possible problem areas is the premature transition from laminar flow to turbulent flow caused by noise interactions with the boundary layer. Laboratory studies have shown that acoustic pressures can interact with the boundary layer causing the flow to transition from laminar to turbulent sooner than it would if there were no acoustic pressures. However, neither the interaction mechanism nor the near field acoustic environment have been studied in detail on large subsonic aircraft. The purpose of this flight test program was to measure the acoustic environment of a large subsonic aircraft in flight and determine the effect noise from this aircraft had on a laminar flow section (gloved onto the existing wing) of the aircraft wing.

Approach - A portion of the 757 aircraft wing was covered with a gloved section to obtain a large area of natural laminar flow (see circular photo). Several measurements to determine the extent of laminar flow in this section were obtained along with fluctuating pressures on the wing. Data were obtained at various altitudes, aircraft speed, engine power setting, and angle of attack. The Boeing Company, under contract to NASA Langley, designed, fabricated, and installed the glove on a 757 and conducted the flight test.

Accomplishment - The flight test was successfully conducted. Measurements indicated that laminar flow was maintained over the wing at about the design criteria and that for this configuration the engine noise did not have a significant effect. However, the noise spectra are unique for each engine design and installation; therefore, these results may not cover all possible aircraft designs. Shown in the photograph are the fluctuating pressures measured on the surface of the wing near the leading edge for both the upper and lower surfaces. These data are for the aircraft operating at an altitude of 40,000 feet and a speed of 0.8 Mach number. With the engine mounted below the wing, significant variations in pressure were not observed on the upper surface at the measurement location with increased engine speed, while on the lower surface at the measurement location, the level at the peak frequency increased by more than 10 dB. In addition, at the lowest engine speed the levels on the top surface were higher by about 6 dB than the lower surface.

Future - Continued analysis of the flight data is being planned. Specifically, sources for the fluctuating pressures will be determined using existing analytical techniques to aid in their identification. Comparisons with stability analysis calculations identifying frequencies of greatest amplification will be compared to the levels of the measured acoustic pressures to help in determining why there appeared to be little effect on transition.

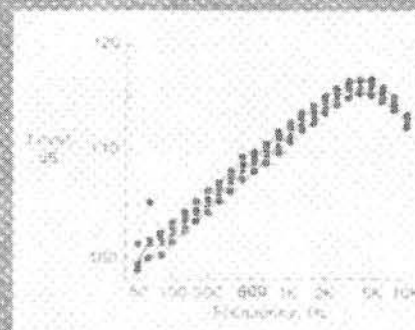
Figure 14(b).

FLUCTUATING LOADS ON A LAMINAR FLOW GLOVED-WING SECTION OF A 757 IN FLIGHT

40,000 ft. Altitude .8 Mach Speed

WING SURFACE

Upper



Lower

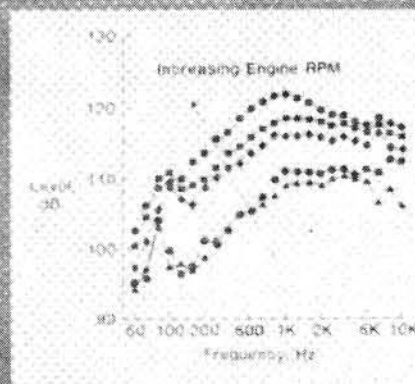


Figure 14(b).- Concluded.

COMPARISON OF MEAN FLOW EFFECTS ON RESPONSES OF A PRESSURE PROBE
AND HOT FILM PROBE TO ACOUSTIC EXCITATION

Tony L. Parrott
Applied Acoustics Branch

Michael G. Jones
Kentron International

Extension 4312

Research Objective - Develop and compare techniques for measuring coherent acoustic excitation in subsonic flow environments.

Approach - The coherent fluctuating Reynolds number due to acoustic excitation was measured in a duct with flow of Mach 0.5. The measurements were conducted using both a pressure probe and a hot film sensor probe. Fluctuating Reynolds numbers were calculated from pressure responses via the acoustic convected wave equation. Probe responses were compared against those of a flush-mounted pressure sensor in the wall.

Accomplishment - Comparisons of the probe responses referenced to mean flow values are depicted in the figure. Dimensionless driving frequencies based on duct height are included in the symbol legend. Symbols of one type cover a sound pressure range of 10 dB. The solid line is a least-square fit whose slope is given in degrees on the figure.

The hot-film probe responses deviated from perfect agreement amounts by about 3 dB. Considering the number of interacting variables involved, the results are encouraging. The pressure probe responses deviated by no more than 1 dB from a line of perfect agreement. This behavior was consistent with increasing Mach number and is believed due to flow induced impedance changes of the sensing ports in the pressure probe.

FUTURE PLANS - The results will be applied to improving the confidence and level of precision in the measurement of in-flight acoustic excitation of boundary layers that is believed to play a role in laminar to turbulent transition.

Figure 14(c).

COMPARISON OF HOT FILM PROBE & PRESSURE PROBE
RESPONSES TO ACOUSTIC EXCITATION
IN MEAN FLOW OF MACH 0.5

SYM	FREQ	KH
X	500 HZ	0.231
□	1000 HZ	0.463
○	1500 HZ	0.694
△	2000 HZ	0.925
◇	2500 HZ	1.156
▽	3000 HZ	1.388

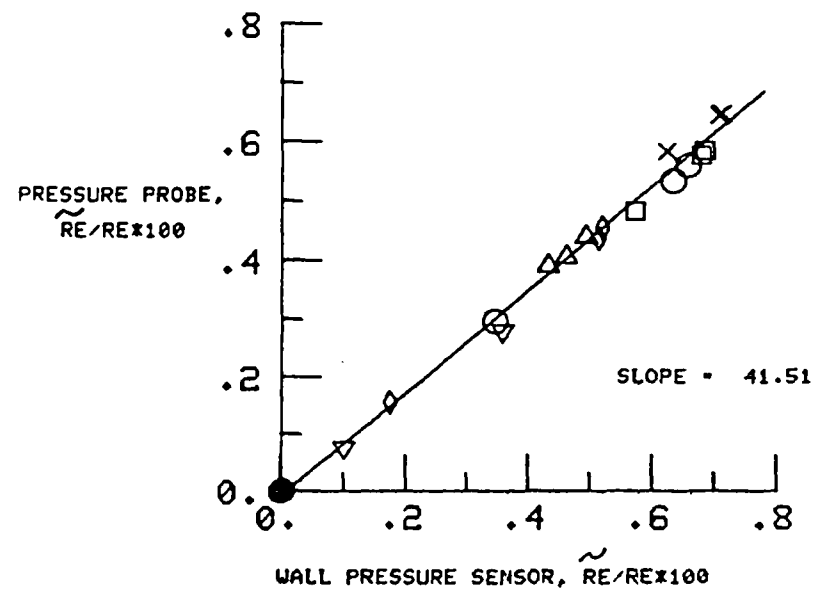
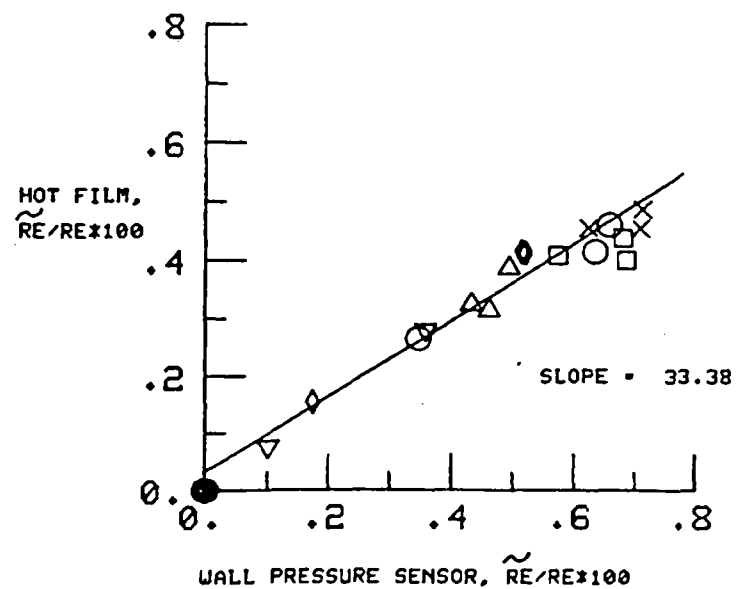


Figure 14(c).- Concluded.

CALCULATING ADMITTANCES OF TEST SPECIMENS IN DUCTS WITH FLOW GRADIENTS IN TWO CROSS-SECTIONAL DIRECTIONS

Willie R. Watson
Applied Acoustics Branch
Extension 4307

Research Objective - The objectives of the research was to develop an analysis to determine the admittance of a test specimen when its aerodynamic environment contains a mean flow with flow gradients in two cross-sectional directions; and if flow gradients in the second direction have a significant impact on the specimen's admittance.

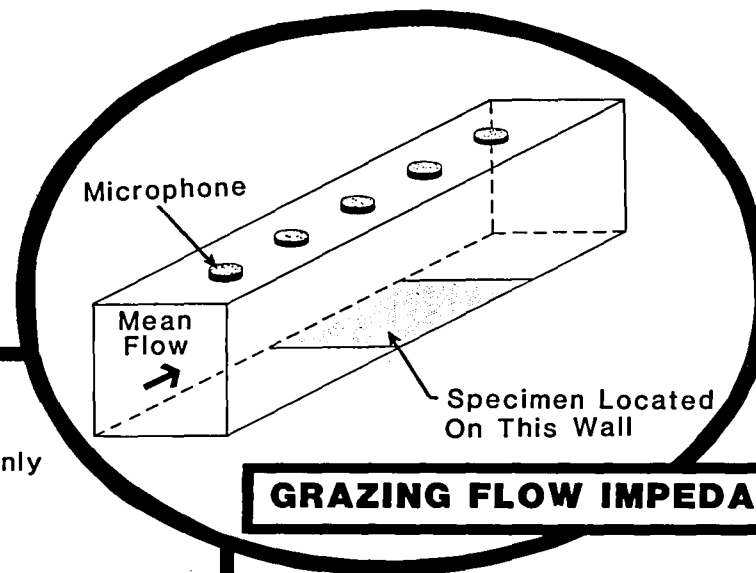
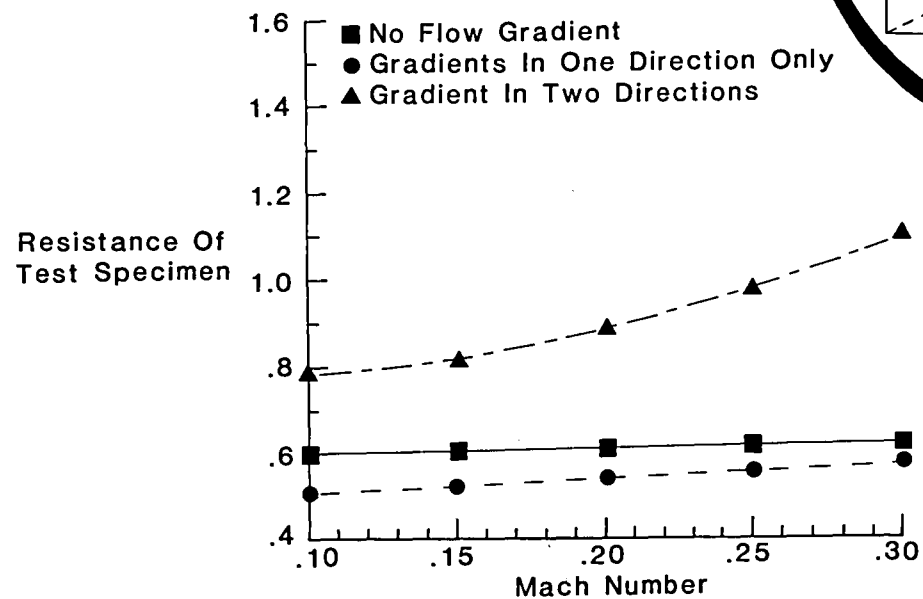
Approach - The approach is to obtain values of the axial and free space wave number, mean flow profile, and specimen wall pressure. These quantities are then used as input to a finite element discretization of the acoustic field. This discretization leads to a generalized eigenvalue problem which is solved to obtain the admittance of the test specimen.

Accomplishments - The matrix equations governing the admittance of the test specimen have been derived. An out-of-core solution to these matrix equations has been obtained. Results of the method have been compared to exact solutions which can be obtained for mean flows without flow gradients, and with results of other authors for some flow profiles which have gradients in only a single cross-sectional direction. Excellent comparisons were obtained in both cases. The analysis has been used in conjunction with experimental data obtained by Mr. Tony L. Parrott in the Langley Flow Impedance Tube Facility. A sketch of the experimental setup is shown in the upper right-hand corner of the figure. The axial array of microphones were used to obtain decay rate data, while the mean flow profile was obtained by aerodynamic measurements. Predicted resistance values in the figure were obtained at 2500 Hz. Results indicate that flow gradients in the second cross-sectional direction have a significant impact on the resistance of the specimen at the high Mach number values.

Future Plans - No future work is planned.

Figure 14(d).

EFFECTS OF FLOW GRADIENTS ON ACOUSTIC RESISTANCE



GRAZING FLOW IMPEDANCE TUBE

Figure 14(d).- Concluded.

EFFECTS OF SOURCE SEPARATION AND PHASING ON POWER DEVELOPED IN A SEMI-REVERBERANT ENCLOSURE WITH APPLICATION TO ACTIVE NOISE CONTROL

Tony L. Parrott
Applied Acoustics Branch, NASA LaRC

David B. Schein
The George Washington University

Extension 4312

RESEARCH OBJECTIVE

Investigate potential benefit of active noise control by performing analytical investigation of source separation and phasing effects on power developed in a semi-reverberant enclosure.

APPROACH

Two prescribed source distributions were located opposite an absorbing wall in an otherwise hardwall rectangular enclosure. Acoustic power developed by the interacting sources was calculated as a function of frequency with source separation and phase as parameters.

ACCOMPLISHMENT

The figure presents power versus frequency for three source conditions; (1) the noise source, operating alone, (2) a control source turned on in phase and located five source widths from the noise source and (3), an out of phase condition for the control source. Note that dimensionless source separation, kd , is given along with the frequency scale. The crosshatched regions represent frequency ranges of noise reduction and the dotted regions represent frequency ranges of noise increase. These results can be explained on the basis of preferential mode excitation for different source spacings and relative phases. The observation that substantial power reduction is obtained at this significant source separation is encouraging.

FUTURE PLANS

This work is being continued with more elaborate source distributions on opposing walls and with absorbing side walls to simulate an aircraft fuselage environment.

Figure 14(e).

POWER INTO SOFTWALL

SOURCE CENTER SEPARATION : 5 Source Widths
40 - 50 Hz

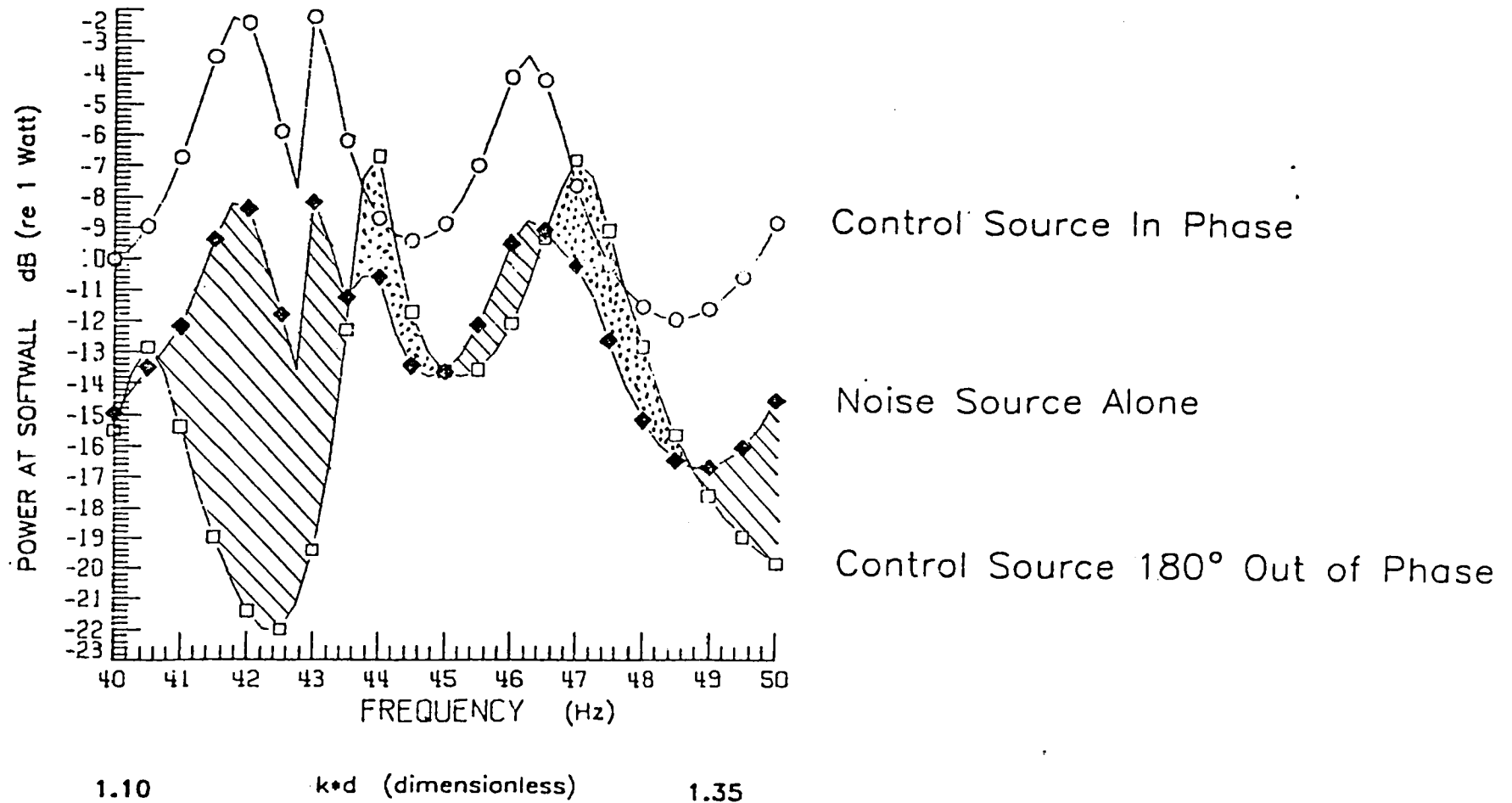


Figure 14(e).- Concluded.

NASA/AHS HELICOPTER NOISE REDUCTION PROGRAM

Otis S. Childress
Applied Acoustics Branch
Extension 4302

Research Objective

The objective of this research is to develop the prediction technology for a design capability for reduced far-field noise of rotorcraft.

Approach

To assign research tasks to the four participating helicopter companies (Bell, Hughes, Sikorsky, Boeing Vertol) consistent with program objectives and to integrate this research with government in-house research. To provide government technical assistance to industry when and where appropriate.

Accomplishments:

Noise prediction.- A review and evaluation of the state of the art of helicopter noise prediction methodology has been accomplished. The results of this review will aid in the understanding of what can currently be done and in the formulation of future research efforts. Companies have in-house capability to run ROTONET or ROTONET modules. Aerodynamic and aeroacoustic analysis programs have been upgraded and this effort is continuing. Conversion of selected in-house programs are being converted into ROTONET modules. Predictions of helicopter high-speed fly-over noise have been made and compared with flight measurements using "improved" semiempirical prediction methods with improved results.

Testing and data base.- The primary effort in this area to date has been the planning and preparation for wind tunnel testing of scale model rotors. Both the government and industry have reviewed the acoustic capabilities of their wind tunnels. Modifications to some tunnels have been accomplished and studies of others continue. Flight data have been acquired on a number of production aircraft for first-order analysis.

Noise reduction technology.- A design has been completed to modify a small helicopter for two-speed main rotor operation. The lower rotor speed will be used for terminal area operations for lower noise radiation. Some work is continuing on the "no-tail rotor" concept. Testing of a "ring-fin" concept for the tail rotor has been completed. These data will be compared to data for the same rotorcraft without the "ring-fin." The results of this effort should define any noise reduction potential of this concept. Preliminary analysis to identify noise reduction potential of blade and tip shape combinations have started.

Figure 15(a).

NASA/AHS HELICOPTER NOISE REDUCTION PROGRAM

CONTINUED

Criteria Development.- One experiment to determine the relationship of helicopter noise to community response has been conducted. A controlled noise exposure field study was conducted in a residential neighborhood. Investigations into the potential of effecting external noise reductions, in terminal areas, through alternatives to standard approaches and departures have begun.

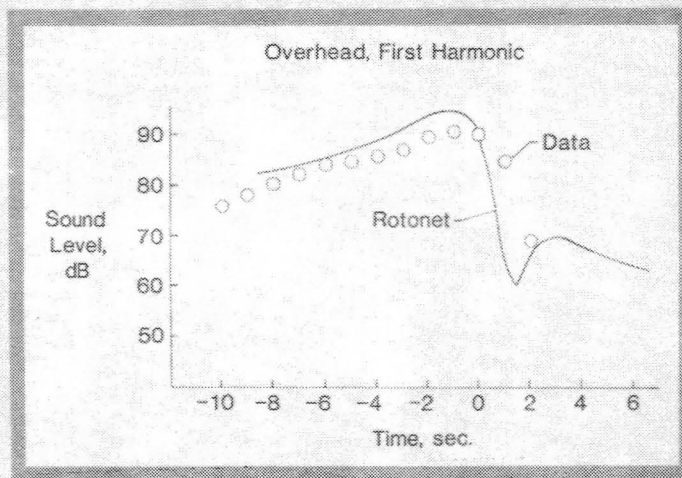
Future Plans

The accompanying figure shows the future direction of the joint NASA/AHS rotorcraft noise reduction program.

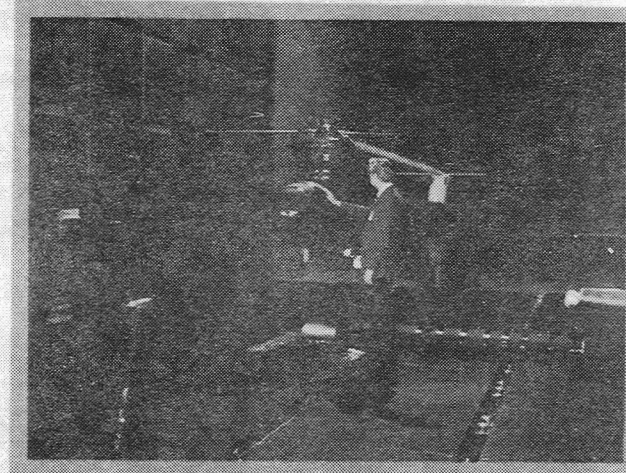
Figure 15(a).- Continued.

NASA-AHS HELICOPTER

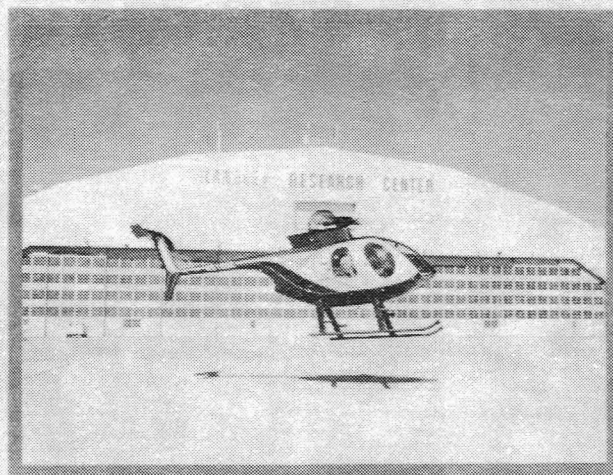
NOISE REDUCTION PROGRAM



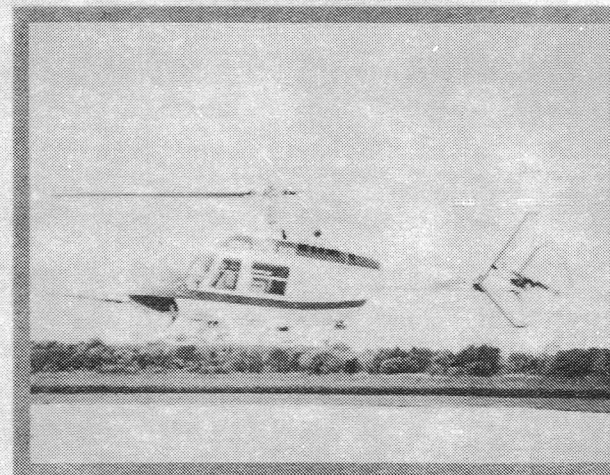
ANALYSIS



WIND TUNNEL TESTS



FLIGHT TESTS



NEW IDEAS

Figure 15(a).- Concluded.

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ROTONET

Robert A. Golub
Applied Acoustics Branch
Extension 3842

Overview - The ROTONET Program is a joint program between NASA and the U.S. Helicopter Industry participating in the NASA/AHS Rotorcraft Noise Reduction Program to develop a comprehensive noise prediction capability for full system helicopter noise.

Objective - The objective is to develop a modular, expandable ROTONET computer code whose architecture employs standardized interfaces, is validated, and is fully documented. This approach will make available to the industry a code which can be used as is, or which can be interaced with, by each user replacing or adding their own in-house developed modules to the code.

ELEMENT STATUS - A baseline code has been developed and installed on the LaRC CDC computer system. The existing code is the initial attempt at establishing a computer code architecture. The architecture developed is modular, allows for future expansion, employs standardized interfaces between modules, and is fully documented.

The code structure is divided into four parts: 1) main and tail rotor blade geometry, 2) rotor performance, 3) noise calculations, and 4) noise propagation and EPNL calculation. The modular architecture and documented interfaces allow noise predictions to be performed either (a) starting with helicopter geometry in part 1), or (b) the required data can be presented directly into parts 2) or 3) and the balance of the noise prediction carried out.

Figure 1 shows the results of comparisons of main rotor code predictions with corresponding main rotor experimental data. The rotor performance prediction was performed for the H-34 helicopter and compared to H-34 experimental blade pressure data. Although the blade section load trends are similar, the predictions show a lack of activity at the blade tip as shown in the experimental data. The main rotor tone noise prediction was performed for, an compared to, data measured from a Dauphin 365C helicopter. The prediction and experimental data are for the helicopter blade-passing frequency with the helicopter flying directly overhead an observer at a speed of 150 knots and at an altitude of 150 meters. While

Figure 15(b).

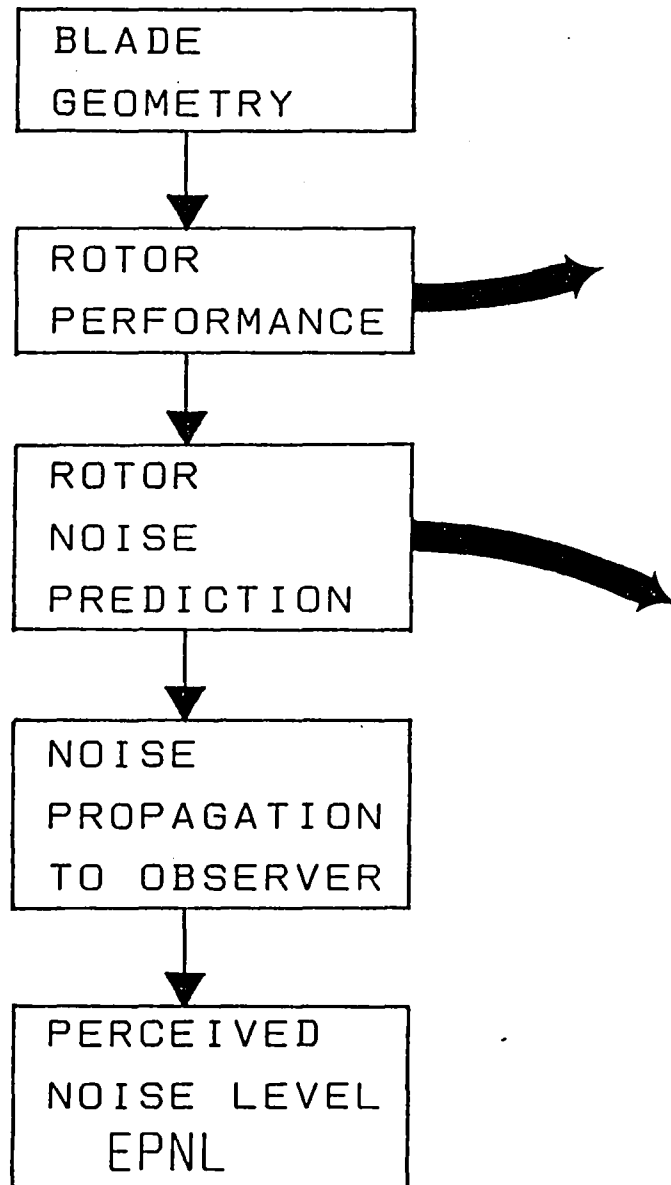
ROTONET

CONTINUED

the agreement for this case is reasonable, comparisons for the higher harmonics and the advancing sideline flyovers clearly point to the need for code improvement.

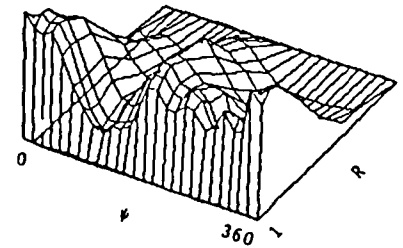
Work has been initiated on a second generation code which will account for higher harmonic blade loading and blade motion, nonprediction theory, and rotor broadband noise.

ROTONET

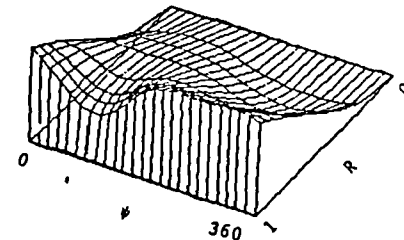


BASELINE ROTONET PREDICTION

H-34 SECTION LOADS - FLIGHT 15



DATA



LRP PREDICTION

DAUPHIN 365C MAIN ROTOR TONE NOISE

OVERHEAD FLYOVER

FIRST HARMONIC

BASELINE ROTONET SYSTEM

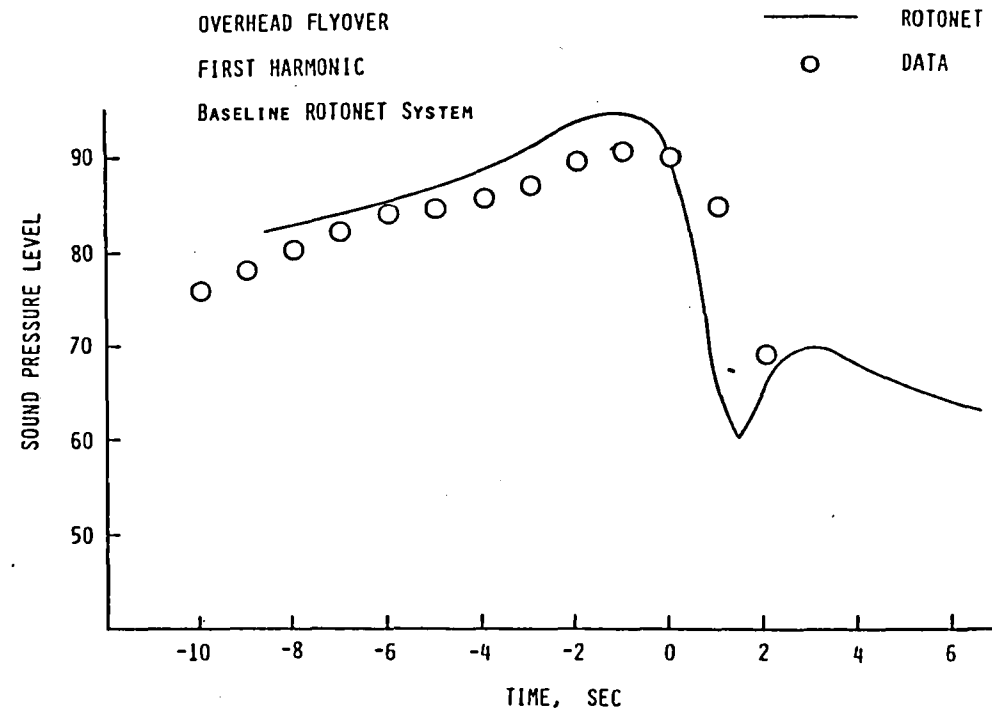


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EVALUATION OF SCALE-MODEL EXPERIMENTAL SETUP FOR STUDYING SOUND PROPAGATION
AT SMALL ANGLES OF INCIDENCE OVER GROUND TERRAIN

T. L. Parrott and I. A. Carlberg

Applied Acoustics Branch
Extension 4312

Research Objective - The objective of this experiment was to develop and evaluate a scale-model experimental setup that would permit parametric validation of long range sound propagation models.

APPROACH - In addition to the effect of sound absorptivity by the terrain, long range propagation of sound at near grazing incidence is influenced by the dynamics of the propagation medium and by terrain irregularities both of which can be described only in a statistical sense. Experimental validation of proposed propagation models can be conducted more efficiently in a controlled scale model environment. This highlight presents a preliminary result from an experimental setup designed to conduct such studies.

The accompanying figure shows the experimental setup consisting of an array of 1/8-inch microphones and a high frequency (5-25 kHz) point source of sound installed in a 20' X 24' flat, smooth plywood surface fitted with a curved, convex peripheral boundary surface to minimize wave diffraction from the edges. The microphone and source heights above the plywood surface could be adjusted continuously to 1.4" and 2.3" respectively. The apparatus was located in an anechoic chamber to simulate propagation over a surface of infinite extent at an acoustic scale factor of about 100:1.

Accomplishment - The plot in the figure shows the relative distribution of sound pressure levels at 12.5 kHz along the radial microphone array for both a hard (open symbols) and soft (shaded symbols) surface. Multiple runs at an incidence angle of about 3 degrees indicate the variability of the data. The soft surface condition was achieved by covering the plywood surface with a 1/8inch-thick layer of felt.

The data variability for the hard surface exhibits acceptable scatter whereas the soft surface data have significant scatter at the more distant microphone locations. This scatter is likely due to a a loss of signal strength because of the limited output of the sound source. It should be noted however that the 1/8-inch felt-covered surface probably represents the most absorptive surface of interest in scale model propagation experiments of this type.

Future - Experimental evaluation of the plywood and felt-covered surface impedances will be obtained. These data will be used in a propagation model to further evaluate the feasibility of this approach.

Figure 16(a).

SCALE MODEL SHALLOW ANGLE PROPAGATION EXPERIMENT

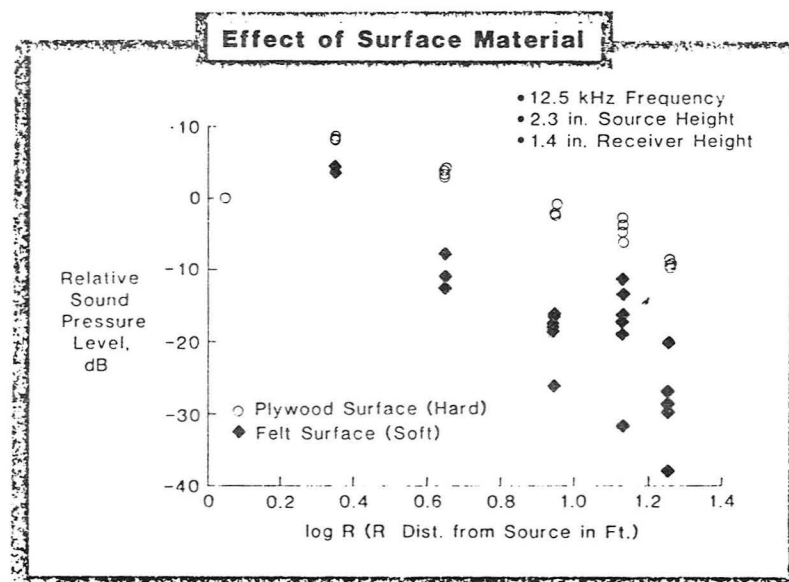
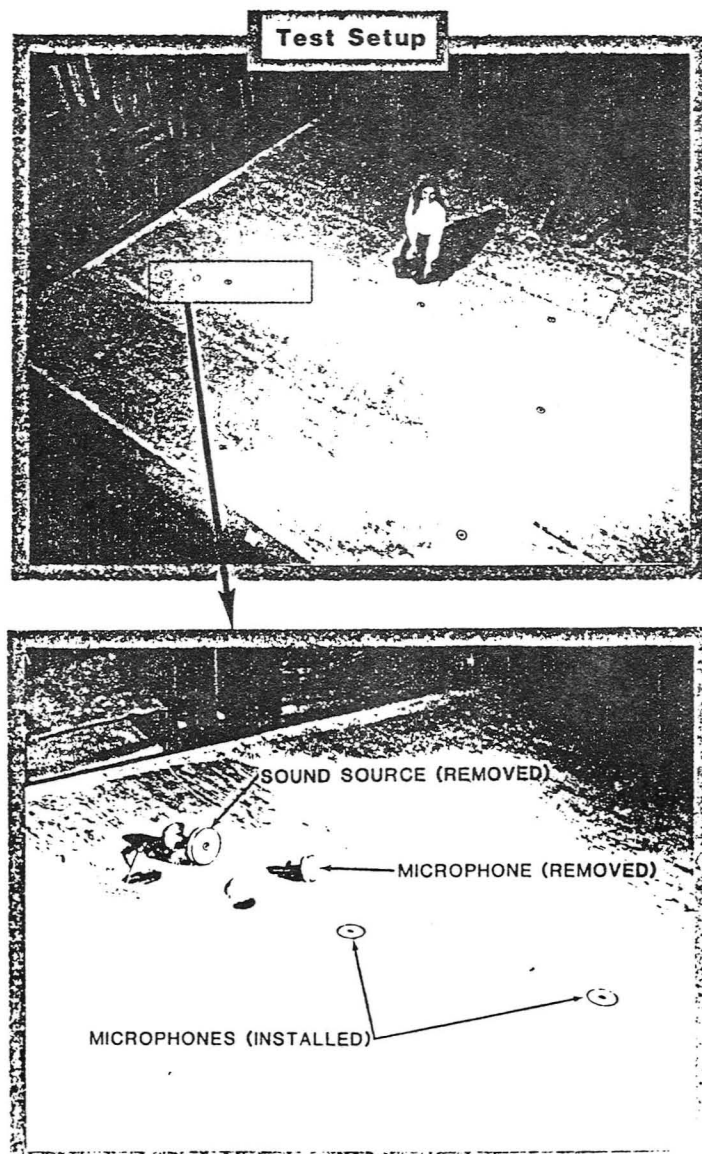


Figure 16(a).- Concluded.

PROPAGATION NEAR AN ACOUSTIC SHADOW ZONE CAUSED BY A LAPSE TEMPERATURE GRADIENT

William L. Willshire, Jr.
Applied Acoustics Branch
Extension 4310

Research Objective - To measure the effects for theory validation of vertical temperature gradients on the propagation of sound above a finite impedance surface.

Approach - Outdoor acoustic propagation problems of interest today often involve distances of 5 to 10 miles. Prediction of sound propagation over such long distances requires an understanding of several topographical and meteorological effects, one of which is refraction due to vertical gradients of sound speed which depend in turn on temperature and wind gradients in the lower atmosphere. The effects of refraction can be larger than the effects of absorption, spherical spreading, and ground impedance, the three most commonly modeled acoustic propagation effects. A theoretical model of propagation in the lower atmosphere above a finite impedance boundary that includes refraction effects due to temperature gradients has been developed under a grant at the University of Utah. An outdoor experiment was conducted at Wallops to obtain data for comparisons with the model.

Accomplishment Description -The experiment, conducted in October 1984, consisted of a variable height source apparatus and a fixed vertical ten-microphone array. Both may be seen in the top two photographs of the figure. Both periodic and broadband noise in the frequency range of 100 to 8000 Hz were broadcast with the source. The source height was varied between 2 and 11 m and the horizontal distance between the source and microphone array was 154 m. The experiment was performed over grass and concrete to make measurements over a ground impedance range. In all, 46 runs were completed with vertical temperature gradients ranging from isothermal to medium strength lapse (decreasing temperature with height). A 6-meter high, 18-transducer weather profiler in conjunction with a tethered weather balloon instrumentation package was used to measure the weather conditions for a particular run.

An example of theory/experiment comparison is given in the bottom portion of the figure. The lapse temperature profile used in the theoretical prediction which was based on actual temperature measurements is shown in the left of the figure. The agreement between theory and measurement is fair. Both show a shadow zone developing close to the ground and an interference pattern above the shadow zone. With a zero temperature gradient, the sound level at the ground would be a maximum; with a temperature lapse the ground sound level is less than a maximum. This area of lower levels due to refraction near the ground is referred to as the shadow zone and is of great importance when predicting sound levels close to the ground. The different position of the lowest interference dip in the theoretical prediction and the measured data indicates a difference in phase between direct and reflected/refracted waves, the cause of the interference pattern, in the measurement and in the theory.

Figure 16(b).

PROPAGATION NEAR AN ACOUSTIC SHADOW ZONE CAUSED BY A LAPSE TEMPERATURE GRADIENT

CONTINUED

Future - Continued theory validation with experimental data is planned. In particular, the sensitivity of fitting the measured temperature profile to a particular mathematical form which is required to perform the analysis will be studied to determine its impact on the quality of the theory/measurement agreement. Three-dimensional plots are being generated to illustrate refractive effects as a function of frequency.

Figure 16(b).- Continued.

SOUND PROPAGATION IN A THERMALLY INHOMOGENEOUS ATMOSPHERE ABOVE A FINITE IMPEDANCE SURFACE

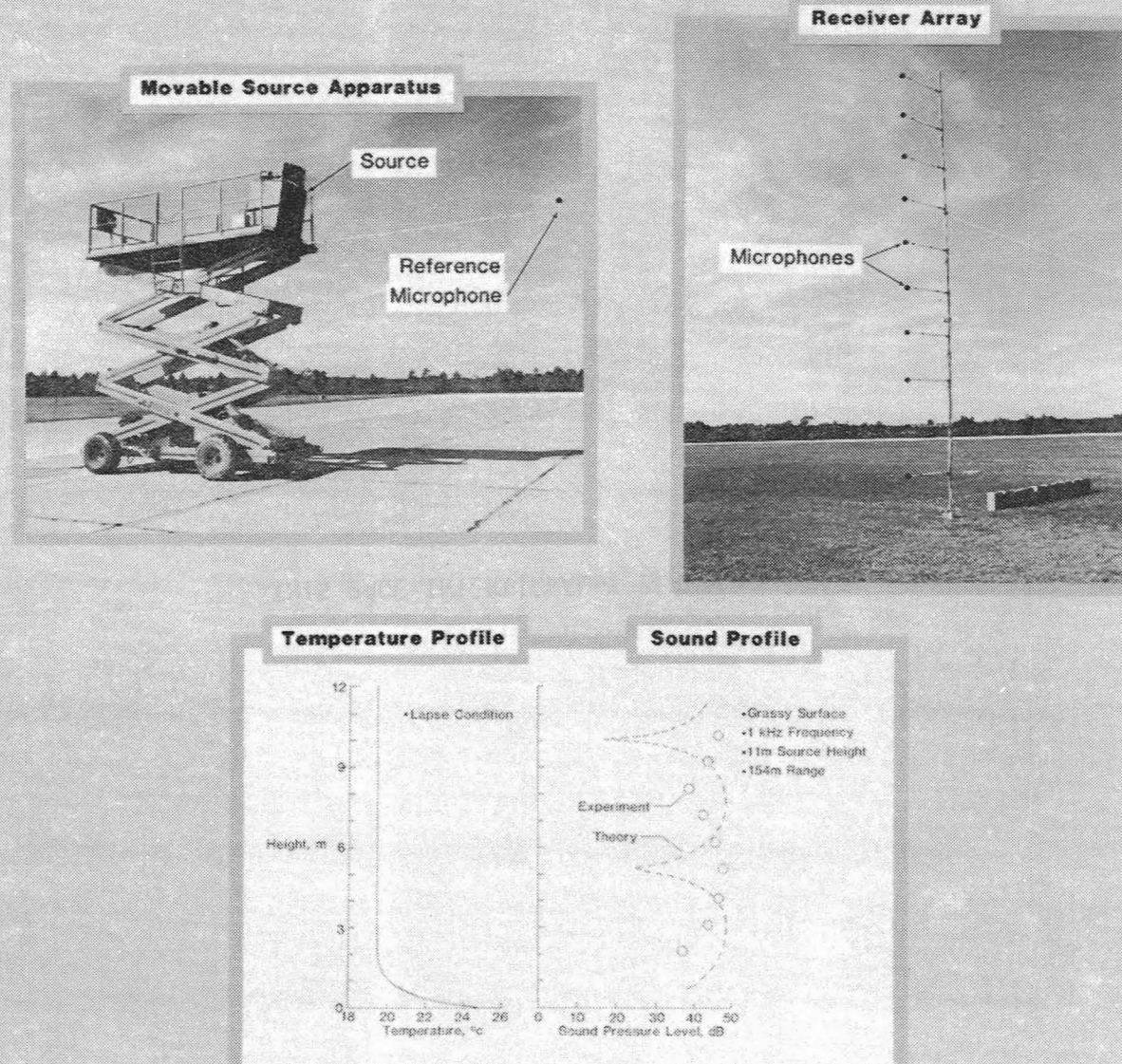


Figure 16(b).- Concluded.

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DIRECTIVITY CHARACTERISTICS OF PUSHER PROPELLER NOISE

P. J. W. Block
Applied Acoustics Branch
Extension 4910

Research Objective - To obtain the data base necessary for evaluating current prediction technology in the area of propeller installation design for subsonic aircraft.

Approach - Noise experiments in the Langley Quiet Flow Facility provided a data base from which to infer noise trends for single-rotation and counter-rotation propellers in tractor and pusher installations. These tests were conducted under a cooperative agreement with Douglas Aircraft Corporation and Hamilton Standard.

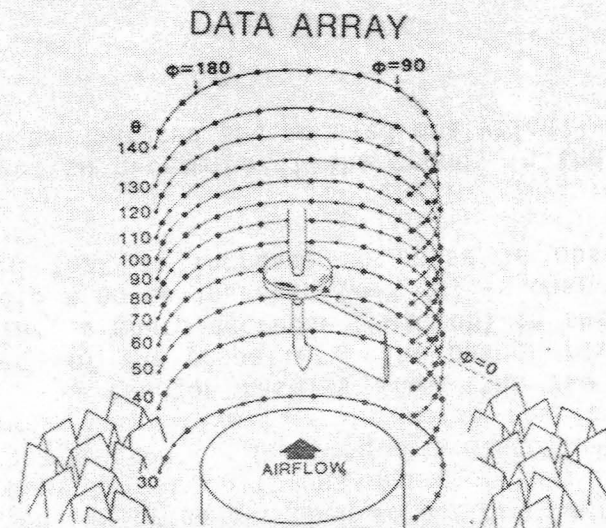
Accomplishment Description - Introducing a wake into an operating propeller has been shown to increase the noise that is generated by the propeller. Experimental studies have shown that these noise increases are directional requiring a thorough mapping of the radiated noise for a complete description. An experimental study was designed to obtain a better understanding of pusher propeller noise in which a vertically traversing circular microphone array was used as shown on the left of the attached photo. A pylon attached to a dummy nacelle which was upstream of the propeller produced the wake. The array of measurement positions and coordinate system is shown in the upper right of the photo. The angles θ and ϕ , which are used to describe the directivity of the pusher noise data, represent the flyover angle and azimuthal angle respectively. The noise results for the tractor and pusher installation are given in the lower right. The tractor results show that the noise is concentrated in a relatively uniform band in the plane of rotation of the propeller. The pusher results show that the wake produces a nonuniformity in this plane. In particular, a sharp decrease (~ 10 dB) in the noise is observed normal to the pylon ($\phi = 90^\circ$). On either side of this dip a noise increase (~ 8 dB) is observed which extends upstream. Reverse rotation results (not shown) revealed that an increase in noise is observed for $\phi = 270^\circ$; however, no dip is present.

Future Plans - The prediction capability in ANOPP will be exercised to determine if the trends in the data are reproducible. Also, data from the counter-rotation propeller will be analyzed and modeled analytically.

Figure 17(a).

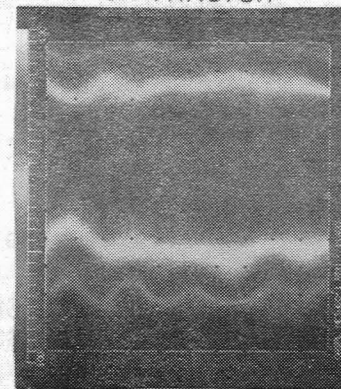
PROPELLER INSTALLATION NOISE TEST

QFF TEST

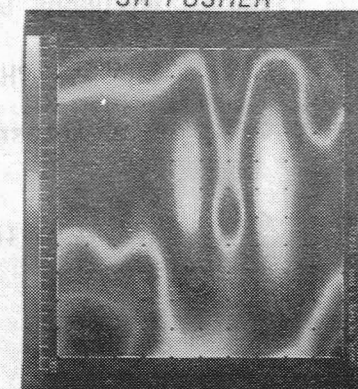


RESULTS

SR TRACTOR



SR PUSHER



Propeller plane

Normal to pylon

Figure 17(a).- Concluded.

SINGLE AND COUNTER ROTATION PROPELLER NOISE COMPARISON

Patricia J. W. Block
Applied Acoustics Branch
Extension 2645

Research Objective - To provide the technology base for incorporating noise tradeoffs into propeller installation design for subsonic aircraft.

Approach - Experiments will provide a data base from which to infer noise trends for various installations and from which to validate existing analytic noise prediction methods.

Accomplishment - Noise measurements of several propeller installations have been made in the Langley 4- x 7-M tunnel. These installations included single (SR) and counter rotating (CR) propellers in strut mounted pusher and tractor configurations as well as at pitch and yaw. This highlight addresses the noise from the SR and CR propellers in the tractor mode at 0° pitch and 0° yaw.

The noise measurements were made by microphones which were flush mounted in a moveable carriage. Eleven microphones were aligned perpendicular to the flow direction at about 13° increments from the propeller axis (see attached sketch). The microphone carriage itself was stepped in the flow direction in 13 positions at 10° increments covering the range from 60° upstream of the propeller disk plane to 60° downstream. For each propeller installation 143 noise measurements were made to define the noise radiation pattern. The comparison shown here is for the two streamwise carriage positions of 40° upstream and 0° (or inplane).

The data shown are free-field corrected noise levels produced by an 8-blade SR2 propeller (16.9" dia.) and a 4 + 4 bladed CR propeller (16.1" dia.). Both propeller configurations were operating at 11,400 rpm and a blade set angle of 12°, forward velocity of 102 fps and nominally 35 lbs. of thrust. These results indicate that inplane, the SR and CR noise is approximately the same. However, upstream of the propeller, the SR noise decreases whereas the CR noise which has considerably higher harmonic content maintains high levels. The azimuthal variation of the CR noise is evident with the peak noise levels occurring where the blades are aligned (-18.75° and 23.5°). At the 40° upstream location differences of as much as 22 dB are observed between SR and CR noise.

Future Plans - The total data set will be reduced to determine the noise characteristics of all installations that were tested.

Figure 17(b).

SINGLE AND COUNTER ROTATION PROPELLER NOISE COMPARISON

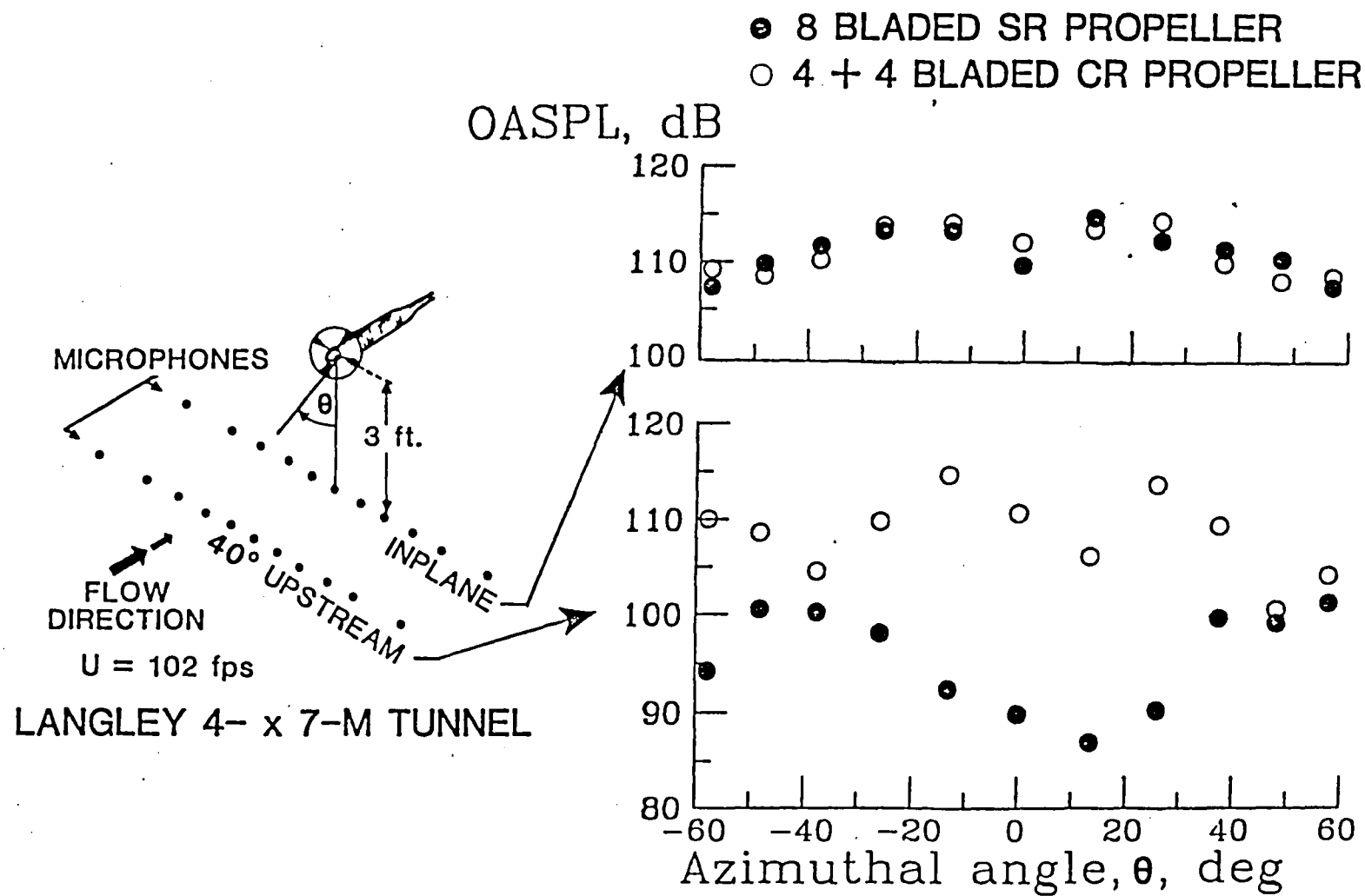


Figure 17(b).-Concluded.

**APPLIED ACOUSTICS BRANCH
FY 86 PLANS**

CIVIL HELICOPTERS

- o COMPLETE BROADBAND PREDICTION IN ROTONET
- o CONDUCT 500-D FLIGHT TEST
- o CONTINUE NASA/AHS NOISE PROGRAM

PROPELLER ACOUSTICS

- o CONDUCT HIGH-POWER SUPERSONIC PROPELLER TEST IN 4- by 7-M TUNNEL
- o ANALYZE AND REPORT SINGLE-ROTATING AND COUNTER-ROTATING PROPELLER RESULTS FROM QUIET FLOW FACILITY

BOUNDARY LAYER ACOUSTICS

- o DEFINE AND CONDUCT FUNDAMENTAL EXPERIMENT OF NOISE INTERACTING WITH FLOW
- o CONDUCT LAMINAR NACELLE FLIGHT TEST WITH LSAD AND GE

ATMOSPHERIC PROPAGATION

- o DEFINE EFFECT OF HIGH WINDS ON NOISE PROPAGATION
- o INITIAL RESULTS FOR PROPAGATION SCALE MODELING

APPLIED ACOUSTICS BRANCH

FY 86 PLANS: NARRATIVE

CIVIL HELICOPTERS

o BROADBAND PREDICTION IN ROTONET

The Rotor Broadband Noise (RBN) module of ROTONET computes the broadband noise for a helicopter rotor due to five noise sources. The user can select any combination of turbulent boundary layer trailing-edge noise, trailing-edge bluntness noise, tip vortex formation noise, laminar boundary layer trailing edge noise, and boundary layer separation noise sources. Each method is based on an empirical data base for a simplified source model which is applied to the rotor geometry accounting for all retarded time and blade motion effects. All sources will have been installed in ROTONET by the end of FY 86 but the Laminar Boundary layer Trailing Edge Noise and Boundary Layer Separation Noise sources will not have been checked out pending the results of a proposed May 1986 wind tunnel test at DNW.

o 500E FLIGHT TEST

Langley Research Center has entered into a joint agreement with the McDonnell Douglas Helicopter Company (MDHC) to conduct noise tests on a flight certified MDHC 500E modified helicopter. The purposes are to study helicopter broadband noise characteristics, noise directivity patterns, noise propagation, and to collect a well defined, high confidence, accurate far field acoustic data base to evaluate a helicopter noise prediction program (ROTONET).

o NASA/AHS PROGRAM

The NASA/AHS program has been involved in full-scale testing, model testing, wind tunnel investigations, and analytical and prediction efforts. Turbulent inflow into a main rotor has been investigated in conjunction with the full-scale Broadband Noise tests. Both of these activities are currently reducing the data from which results are forthcoming. The data from the Blade Vortex Interaction tests are being reduced and formatted for analysis. A follow-on test to the Broadband Noise tests is planned for the spring and will be a flight test investigation. These data will be used to compare with the ground test data base to investigate the extent to which the ground test data can be extrapolated to flight and as a part of the ROTONET validation data base. Data analysis of other full- and model-scale tests, such as the main rotor/tail rotor interaction tests and the ring fin tests, will continue. Analytical efforts to-date have given some encouraging results and indicated new directions in which investigations should proceed. Analytical efforts in these new directions will start in 1986. It is expected that most program participants will have on-line ROTONET capability by the end of 86 and begin integrating this capability into their present systems.

Figure 19.

APPLIED ACOUSTICS BRANCH

FY 86 PLANS: NARRATIVE Continued

PROPELLER ACOUSTICS

o DIRECTIVITY AND TRENDS OF NOISE GENERATED BY A PROPELLER IN A WAKE

An experimental study of the effects of pylon wake on far field propeller noise was conducted using a model scale SR2 propeller in a low-speed anechoic wind tunnel. This study was done through a cooperative agreement with Douglas Aircraft Corporation and Hamilton Standard. A detailed mapping of the noise directivity was obtained at 10 test conditions over the propeller operating ranges $.456 < M_T < .722$ and $.12 < \text{SHP}/d^2/B < 4.26$. The variation of the noise penalty between a tractor and pusher installation with the flyover angle, θ , and the circumferential angle ϕ were analyzed. The noise penalty associated with a close versus far pylon spacing (spacing penalty) was similarly investigated. The trends in these noise penalties with M_T and SHP were found for selected values of θ and ϕ . The data analysis is expected to be completed in FY 86. One NASA TP has been prepared for publication and two conference papers are being written.

o SUPERSONIC TIP SPEED PROPELLER NOISE TESTS IN 4- BY 7-M TUNNEL

Hardware is being designed for a wind tunnel test involving the swept CRPX1 propeller operating at supersonic tip speeds and high loading. The CRPX1 is a 5+5 bladed counter-rotation propeller designed by Hamilton Standard, UTRC. The test which is being done in cooperation with Pratt and Whitney Aircraft, will be conducted in the 4- by 7-M Tunnel. Single- and counter-rotation configurations will be examined as well as tractor and pusher installations. Further, the number of blades in each hub can be varied to study the interaction noise separately from the individual blade noise. The tests are tentatively scheduled for the fall of 1986.

o FLIGHT TEST OF A HIGH-SPEED PUSHER PROPELLER

A flight test is being planned with Cessna to obtain near field (fuselage-mounted transducers) acoustic data on a pusher mounted turboprop. The propeller is a five-bladed McCauley design (straight blades). Forward flight speeds of $M = .6$ and propeller helical tip speeds exceeding $M = 1$ will be covered in the test matrix. An MOA negotiated through LSAD permits complete data sharing with Cessna without any data restrictions. Acoustic instrumentation will be supplied to Cessna. Cessna engineers and technicians will mount the instrumentation and record the data. Copies of the data tapes will be sent to NASA for analysis.

Figure 19.- Continued.

APPLIED ACOUSTICS BRANCH

FY 86 PLANS: NARRATIVE Continued

BOUNDARY LAYER ACOUSTICS

o DEFINE AND CONDUCT FUNDAMENTAL EXPERIMENTAL OF NOISE INTERACTING WITH FLOW

An experiment is being defined and hardware is being acquired in order to conduct an experiment in the Quiet Flow Facility aimed at studying the effect of noise on airfoil boundary layer transition (laminar-to-turbulent). The first task is to determine the specific facility operating conditions (mean velocity, turbulence intensity, inflow noise levels) under which laminar flow can be maintained over a significant extent of the airfoil. A semi-span section of a full-scale Laister sailplane will be positioned across the low-speed 4-ft-diameter vertical jet to provide local flow conditions at Reynolds numbers up to 2×10^6 . A recently developed liquid-crystal flow visualization technique will be used to determine areas of laminar flow on the airfoil surface. If successful, a second task will be performed utilizing a simple acoustic source mounted at the focal point of a parabolic dish, providing a plane wave acoustic input to the airfoil boundary layer. Changes in the extent of laminar flow will be measured, and results will be compared with an existing numerical code (SALLY Code) for predicting noise-induced transition.

o CONDUCT LAMINAR NACELLE FLIGHT TEST WITH LSAD AND GE

It has been demonstrated that noise can cause premature transition of the boundary layer from laminar flow to turbulent flow over the surface of an airfoil. Such a transition would cause a loss of the advantages of laminar-flow sections, e.g., an increase in drag. To study the effects of noise on a laminar-flow-designed nacelle, a cooperative program between General Electric, the LSAD, and the AAB of AcoD has been established. The program includes the design and construction of three different flow-through, laminar-flow nacelles to be mounted on the wing of an OV-1 aircraft. Each nacelle is designed to respond differently to a noise input. GE, using in-house procedures, has built these nacelles with an internal noise source. However, because it was anticipated that sufficient control would not be available from this noise source, the AAB has designed and built an external noise source to be mounted on the wing, outboard of the test nacelle. The LSAD has been coordinating all of these activities.

To gain experience in conducting this experiment, the LSAD has "booted" a laminar flow glove on the existing nacelle of a JT15D which is currently mounted on the OV-1. Several flights are being conducted to develop techniques to observe laminar to turbulent transition and define the exact test environment existing in flight. In addition, the external noise source has been tested, in flight, to obtain its operating range for controlling frequency and level on the side of the nacelle. Tests are currently being conducted on the JT15D nacelle and the GE nacelles have been delivered to Langley. Instrumentation is currently being installed in the GE nacelles and it is anticipated that testing will start on these nacelles this spring.

Figure 19.- Continued.

APPLIED ACOUSTICS BRANCH

FY 86 PLANS: NARRATIVE Continued

ATMOSPHERIC PROPAGATION

o INITIAL RESULTS FOR PROPAGATION SCALE MODELING

The propagation scale modeling effort focuses on propagation over natural terrain rather than on man-made structures as has been the interest in the past in noise control and architectural acoustics. This effort is both in-house and under grant activity with The Georgia Institute of Technology. An experiment has been conducted in-house and data analysis is well underway on a fundamental experiment involving a noise source and multiple-receiver near or flush with a ground surface represented by a large, flat plywood platform. The plywood was used both as a primary test surface and also as a base for a felt covering, which served to represent a finite impedance boundary such as grass. The experimental results will be used to evaluate analytical models for very shallow angle acoustic propagation. The grant activity, which is at the start of the second year of a 3-year effort, is both theoretical and experimental. It will focus on analytical model development and experimental validation of two long-range outdoor propagation situations: (1) propagation over irregular topography as represented by an arbitrary radius-of-curvature hill, and (2) propagation of ground with position-dependent impedance.

o EFFECTS OF HIGH WINDS ON NOISE PROPAGATION

Acoustic power generated by a 4-megawatt, 80-meter-diameter wind turbine located at Medicine Bow, Wyoming provided an extensive set of experimental data used to evaluate two different analytical approaches to the study of long-range, low-frequency noise propagation in the presence of high wind. The experimental data were taken at ranges upwind to 4000 m and downwind to 20,000 meters at wind speeds up to 25 meters per second. One analytical approach employs normal mode theory and extends a previous analysis of Chunchuzov (Soviet Phys. Acoust. 1984) for a source in a hard ground plane to the case of interest, an elevated source above a finite impedance ground. The other approach, being performed under grant by The University of Texas at Austin, uses the time-honored ray tracing technique valid in the high-frequency limit. This effort will attempt to quantify its low-frequency limitations.

Figure 19.- Concluded.

STRUCTURAL ACOUSTICS



ATP



Rotorcraft



Composites

INTERIOR ACOUSTICS



Composites

SONIC FATIGUE



Acoustic Loads



Hypersonics

ACTIVE NOISE CONTROL



Modeling



Verification



Implementation

SUBJECTIVE ACOUSTICS



ATP



Sonic Boom



Space Station

Figure 20.

STRUCTURAL ACOUSTICS
FIVE YEAR PLAN

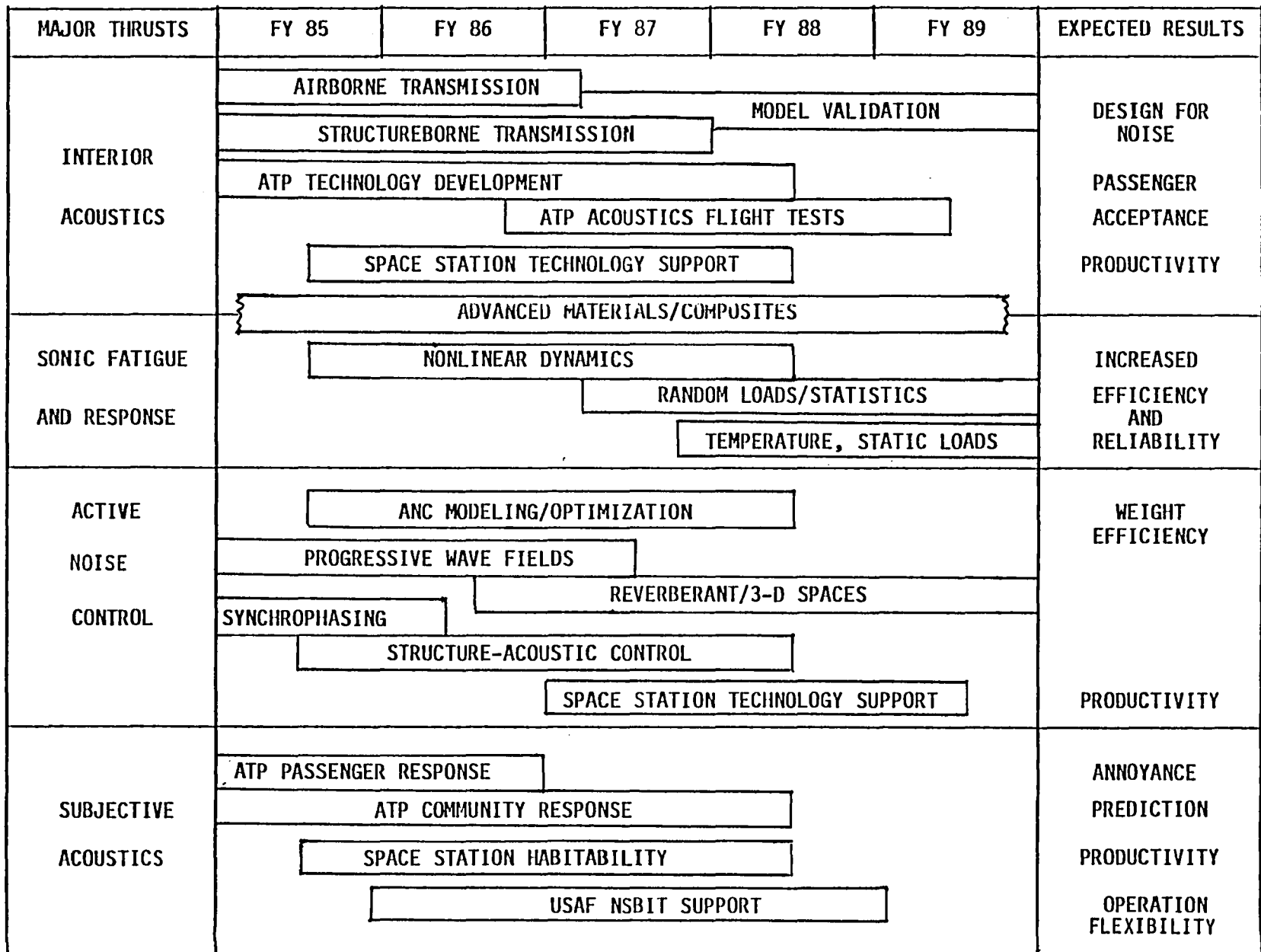


Figure 21.

INTERACTION BETWEEN AIRBORNE AND STRUCTUREBORNE NOISE

Michael C. McGary
Structural Acoustics Branch
Ext. 3561

Research Objective - Further the understanding of noise radiation resulting from combined airborne-structureborne components of the noise radiation of structures for the purposes of controlling and reducing aircraft interior noise.

Approach - An analytical computer program was developed which predicts the noise radiation from structures with simultaneously combined and correlated acoustic and vibrational inputs. An experimental study using simple rectangular plates was performed in conjunction with the analytical study so that the trends predicted by the computer simulations could be verified.

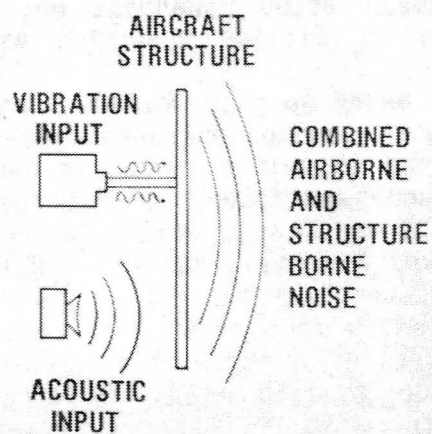
Accomplishment Description - A comprehensive study of the interaction between airborne and structureborne noise radiated by simple structures has been completed. The effects of a number of parameters were investigated. These included: relative magnitude and phase of the acoustic and vibrational inputs; path of propagation of the inputs; added structural damping; and material characteristics of the structure. The results of the study indicate that the interaction between the airborne and structureborne components is much more important than previously believed. The accompanying figure shows (for example) how overall sound power radiated in the 0-1000 Hz frequency range depended on the interaction between the inputs. A structureborne noise with an output power level of 68.6 dB combined with an airborne noise with an output power level of 82.0 dB produces a combined output which can range anywhere from 80.7 dB to 83.3 dB depending on the phase relationship between the two inputs. This is an extremely important result in light of the fact that previous studies have treated the airborne and structureborne as if they were additive components of power output (which produces an 82.2 dB result). The accompanying spectral data curves show the analytical prediction and experimental verification of the large variation in sound power levels due to the interaction between airborne and structureborne noise. The figures show as much as a 10 dB variation in level in some frequency regions when the relative phase of the components is varied.

Future Plans - The analytical method and experimental apparatus will be used to refine a diagnostic tool which separates the airborne and structureborne components of some unknown combination of the two noises.

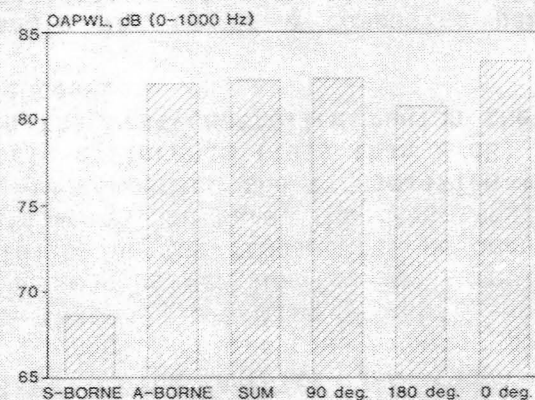
Figure 22(a).

INTERACTION BETWEEN AIRBORNE & STRUCTUREBORNE NOISE

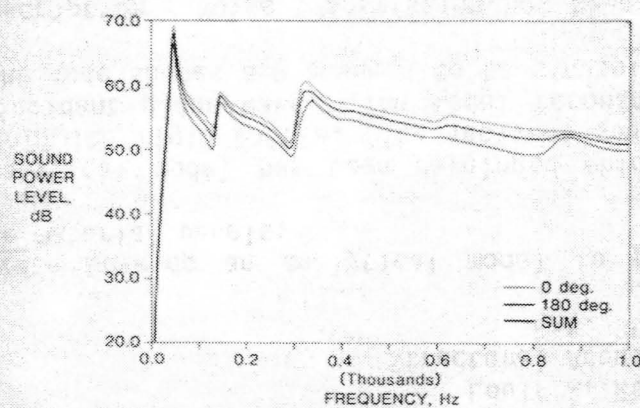
ANALYTICAL & EXPERIMENTAL MODELING



OVERALL SOUND POWER RESULT



PREDICTION OF INTERACTIVE EFFECTS



VERIFICATION OF INTERACTIVE EFFECTS

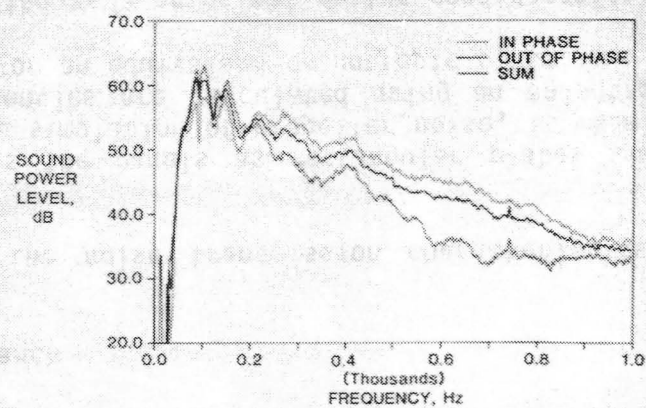


Figure 22(a).- Concluded.

TRANSMISSION LOSS OF FINITE COMPOSITE PANELS

Louis A. Roussos
Structural Acoustics Branch
Ext. 3561

Research Objective - Develop an analytical model to predict the noise transmission characteristics of advanced composite material panels.

Approach - An analytical model has been developed which models the panels as rectangular plates simply supported in an infinite rigid baffle. The incident sound, as a simulation of propeller noise, is modelled as an obliquely incident plane wave. The modal resonant frequencies are calculated using an anisotropic equation, while the mode shapes are assumed to be sinusoidal as for an equivalent orthotropic plate.

Accomplishment Description - Noise transmission has been identified as a principal design consideration for aircraft with composite fuselages. On conventional and advanced turboprop aircraft, most of the noise transmission occurs, or is expected to occur, at low frequency. Because the flexural rigidity moduli of a composite panel have variable directionality depending on ply-angle lay up, panels with different ply-angle lay ups or with different orientations with respect to the incident noise could have markedly different low frequency noise transmission characteristics. Thus, calculations have been performed to obtain some indication of the magnitude of these effects on transmission loss. The results are shown in the accompanying figure for a 14-in. by 8-in. by 0.04-in. graphite-epoxy panel. The curves showing ply-angle effect, which were calculated for the case of normal incidence, show that a panel made of +45°, -45° plies has significantly higher (6 to 14 dB) transmission loss in the stiffness-controlled low frequency region than a panel made of 0°, 90° plies. In the frequency range immediately following the fundamental resonance, the 0°, 90° panel has 2 to 9 dB more transmission loss. Since the panels weigh the same, the transmission loss curves merge together in the high frequency mass-controlled region. In comparing the transmission loss for the +45°, -45° panel for two different angles of incidence, very little difference (less than 2 dB) is seen to occur in the stiffness-and resonance-controlled regions, while in the mass-controlled region the normal incidence curve rises up to a maximum of 3 dB above the 45° incidence case.

These predictions indicate that the ability to tailor the ply-angle lay up of a composite panel can significantly affect the low frequency noise transmission characteristics and also that the effect of varying the angle of incidence is not as important an effect at low frequency. The ply angle effect merits further study.

Future plans - The analytical model will be used to determine the effect of varying the azimuthal incidence angle and then will be advanced to calculate field incidence transmission loss by integrating over a range of incidence angles. A research program to verify the field incidence model by measuring the transmission loss of a variety of small composite panels has begun.

Figure 22(b).

TRANSMISSION LOSS OF FINITE COMPOSITE PANELS

14in. x 8in. x 0.04in. GRAPHITE-EPOXY PANEL

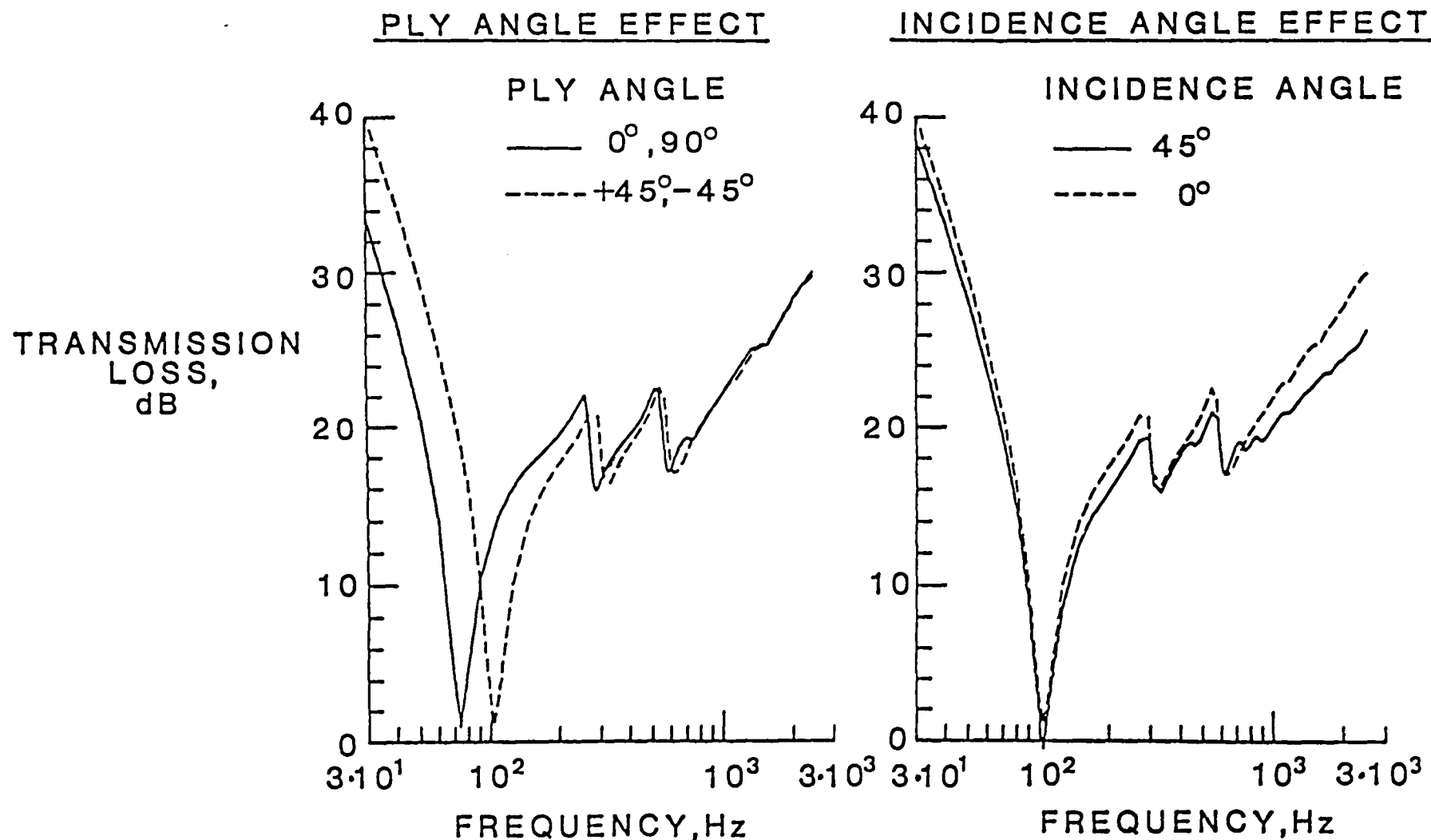


Figure 22(b).- Concluded.

MODAL RESPONSE AND NOISE TRANSMISSION OF COMPOSITE PANELS

Ferdinand W. Grosveld and Vern L. Metcalf
Structural Acoustics Branch
Ext. 3561

Research Objective - To establish a prediction model that describes the field-incidence transmission loss of fiber reinforced composite panels based on the knowledge of their structural modal parameters.

Approach - Model decomposition of the equation of motion for a rectangular, orthotropic, composite panel was used to determine the panel deflection for each model of vibration. To arrive at this solution mode shapes were assumed that satisfy the boundary conditions at the panel's edges. Coupling of the structural and acoustic response is obtained by applying the boundary conditions of velocity and wave potential continuity at the panel's surface. Integrating the ratio of the incident and transmitted acoustic pressures over all participating modes, panel area, and angle of sound incidence then yields the field-incidence transmission loss. Besides mass per unit area, modal frequencies and modal damping are required for input in the transmission loss equation. These modal parameters were obtained from an experimental modal analysis of the composite panels while installed in the NASA Langley transmission loss apparatus. Concurrently, transmission loss measurements were conducted to enable comparison between the experimentally and analytically obtained transmission loss values.

Accomplishment Description - It has been shown analytically that the odd-odd modes are the most important in the transmission loss mechanism especially in the frequency range below 500 Hz where the modal density is low. This is confirmed by the experimental transmission loss values. Calculations and measurements were performed for nine panels, including tape-ply and fabric-ply panels consisting of laminae where fiberglass, graphite or aramid fibers are embedded in an epoxy resin matrix material. In all cases the predicted curve follows the general shape of the measured data, with local minimum transmission loss occurring at the resonance frequencies of the indicated modes. Composite panels are used because of their high strength to mass ratio and will generally exhibit fundamental frequencies that are higher than homogeneous panels that are designed for equal critical shear load. This improves the transmission loss in the frequency region below the fundamental. Of the composite panels used in this study the fabric angle-ply panel has the highest fundamental resonance frequency followed by the fabric cross-ply, tape cross-ply and tape angle-ply panels.

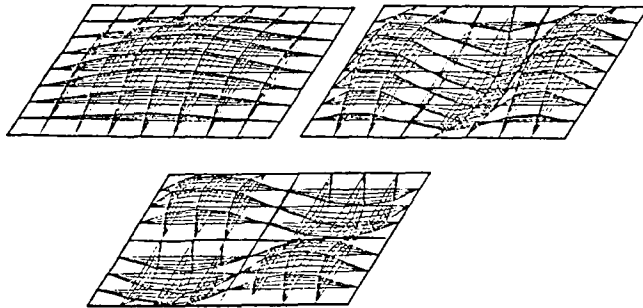
Future Plans - Static boundary conditions will be replaced by the moving edge conditions to analytically describe the panel behavior when the composite panel is part of a vibrating sidewall. The phenomenon of skewed nodal lines for panels with fiber-orientation for a predominant angle will be investigated.

Figure 22(c).

MODAL RESPONSE AND NOISE TRANSMISSION OF COMPOSITE PANELS

Finite Panel TL Theory

Modal Decomposition

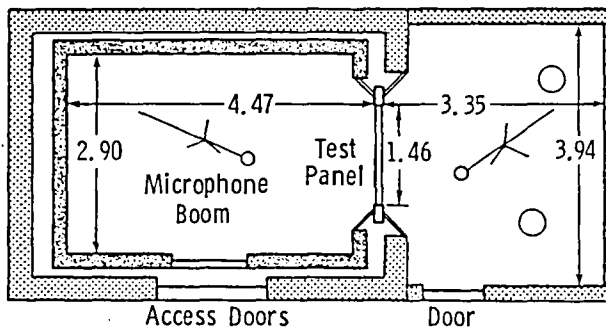


$$TL = 10 \log \left| \frac{G(\theta)}{\sum \sum F(W_{mn}, \xi_{mn}, \mu)} \right|$$

Panel Deflection: $\sum \sum F(W_{mn}, \xi_{mn}, \mu)$

TL Facility

Top View



Measurements

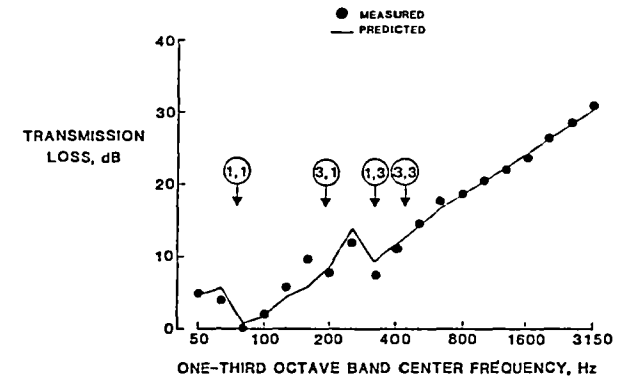


Figure 22(c).- Concluded.

COMPARISON OF NOISE TRANSMISSION PREDICTION FOR COMPOSITE AND ALUMINUM FUSELAGE SECTIONS

Clemans A. Powell
Structural Acoustics Branch
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Research Objective - Develop noise control technology for advanced composite material structures.

Approach - The Lockheed-California Co. designed and constructed a 5.5 ft. diam., 11.2 ft. long graphite-epoxy cylindrical acoustical-test fuselage section to have the same strength characteristics as a Merlin turboprop airplane fuselage as part of the ACEE-ACST contract. The Propeller Aircraft Interior Noise model was modified to allow boundary layer type noise inputs and orthotropic stiffness characteristics and was used to predict the noise reduction of the composite and equivalent strength aluminum structures.

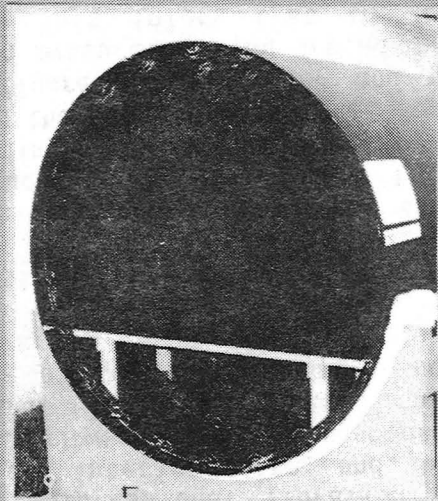
Accomplishment Description - Initial predictions for noise reduction of turbulent boundary type noise have been made by Lockheed for aluminum and composite cylinders with the same light-weight acoustical trim and are indicated in the attached figure. A somewhat surprising result was that the composite structure, which has approximately 15% less skin mass, is predicted to provide significantly higher noise reduction throughout most of the frequency range of interest. This, in retrospect, is attributed to the higher stiffness to mass ratio of the composite skin and resulting increase in panel mode frequencies. The prediction model also predicts the modal behavior of the cylinders and indicated that the modal density of the composite cylinder is less over most of the frequency range. For broadband noise like that produced by turbulent boundary layers, less noise energy can be transmitted in a given bandwidth. The crossover point where the aluminum and composite cylinders have the same modal density is in the 800 Hz one-third octave band.

Future Plans - The composite cylinder has been delivered to the Structural Acoustics Branch and is currently undergoing modal analysis. An extensive set of noise transmission tests are planned and comparisons will be made with earlier measurements by Lockheed on a Merlin fuselage.

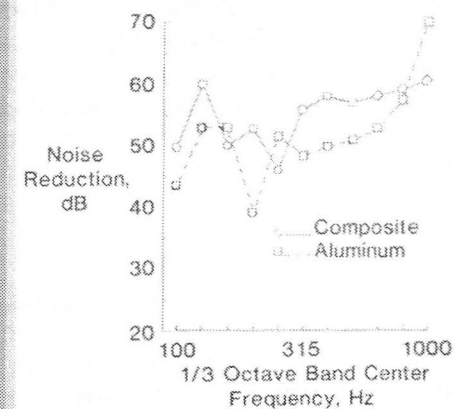
Figure 22(d).

COMPARISON OF NOISE TRANSMISSION PREDICTION FOR COMPOSITE AND ALUMINUM FUSELAGE SECTIONS

Graphite/Epoxy
Composite Fuselage Section



Predicted Reduction
in Boundary Layer Noise



ANALYTICAL PARAMETERS

- Propeller Aircraft Interior Noise Model With Simulated Boundary Layer Noise Input
- Equivalent Strength Aluminum And Composite Cylinders
- Cylinder Dimensions 5.5 ft Diam. x 11.2 ft Long
- Skin Weights Aluminum - 0.88 lb/ft^2 , Composite - 0.76 lb/ft^2
- Trim Weight 0.26 lb/ft^2

Figure 22(d).- Concluded.

STRUCTUREBORNE NOISE MEASUREMENT TECHNIQUE DEVELOPMENT

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Ext. 3561

Research Objective - The objective of this research which is in support of the ATP program, is to develop techniques for measuring and controlling structureborne interior noise for propeller aircraft.

Approach - Because of the high correlation of airborne and structureborne noise in propeller aircraft, it is impossible to determine the source or path of noise inside the aircraft from only interior and exterior noise measurements. The approach of this research, which uses the LeRC OV-10 aircraft, is to obtain transfer functions between measured vibration inputs using electrodynamic shakers (upper left figure) and the flexural and compressional vibration response of the wing of the aircraft; between the measured vibration inputs and interior noise; and, between the wing response and interior noise. By comparing the transfer functions between the wing response and interior noise under flight or ground run up conditions (upper right figure) with those obtained using the measured vibration inputs, it is possible to infer the relative magnitude of the structureborne noise and whether the dominant mechanism of vibrational energy transfer is flexural or compressional.

Accomplishment Description - Vibration and ground run up tests have been started on the OV-10 aircraft at Langley to obtain the necessary transfer functions. Modal analyses of the acceleration of the wing and fuselage structure were made to determine the flexural response of the system to vibration inputs. The mode with natural frequency (106 Hz) closest to the propeller blade passage frequency (100 Hz) was a combined torsional and bending mode as indicated in the lower left figure. Examples of transfer functions between interior noise and the wing compressional response measured with strain gages on the wing spars are shown in the lower right figure for vibration and ground run up tests. The levels of interior sound pressure relative to strain measured during ground run up are about 20 dB greater than those measured with only the vibration input. This infers that the contribution of airborne noise is about 20 dB greater than structureborne noise induced by compressional energy flow through the wing.

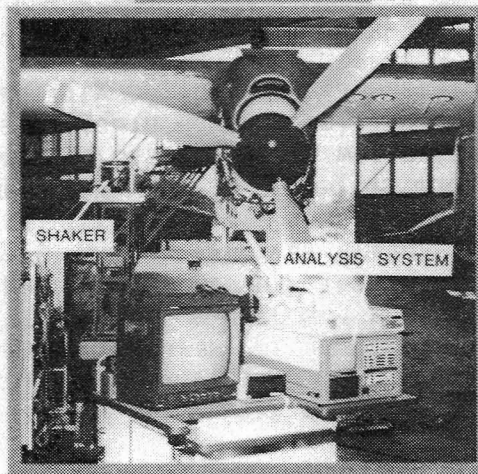
Future Plans - Additional tests are underway to provide a more complete matrix of the three types of transfer functions for different spatial locations of the shaker inputs, strain and accelerometer measurements. Flight tests are also planned to provide differing relative contributions of airborne and structureborne inputs.

Figure 22(e).

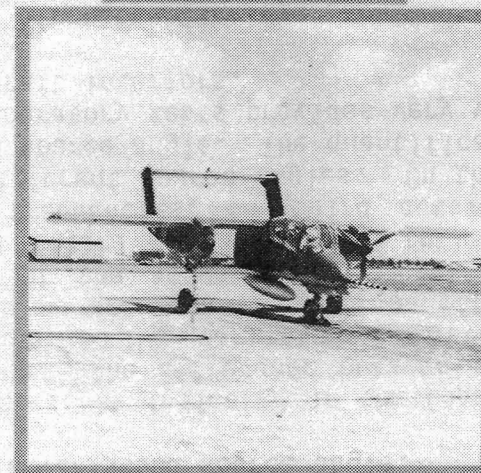
STRUCTUREBORNE NOISE MEASUREMENT TECHNIQUE DEVELOPMENT

OV-10 TESTS

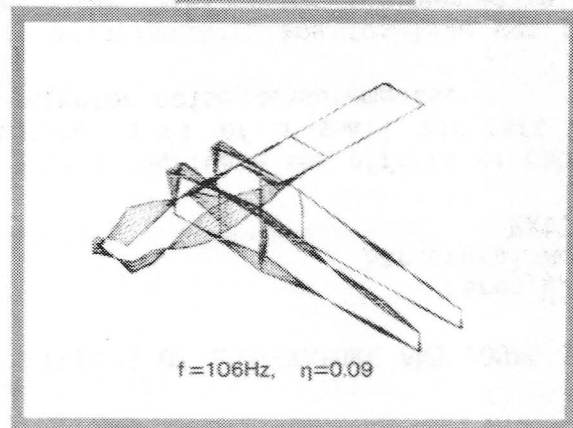
VIBRATION TESTS



GROUND RUN UP TESTS



MODAL RESPONSE



NOISE/STRAIN RESPONSE

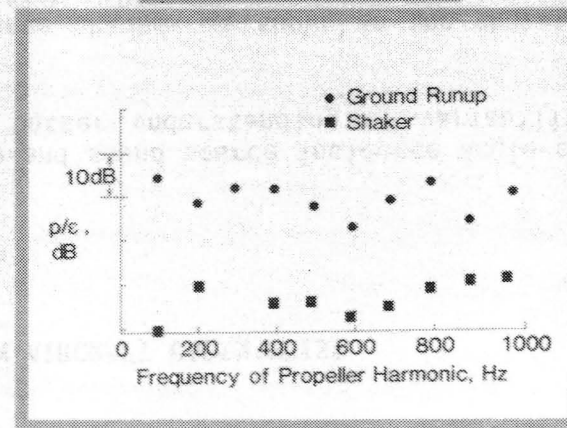


Figure 22(e).- Concluded.

EFFECTS OF TEMPERATURE AND SOUND SOURCE ANGLE ON AIRCRAFT CABIN NOISE

Karen E. Heitman
Structural Acoustics Branch
Ext. 3561

Research Objective - To investigate the effects of cabin temperature and sound source incidence angle on the interior sound pressure level of a small aircraft to provide a better understanding of variability in aircraft in-flight interior noise measurements.

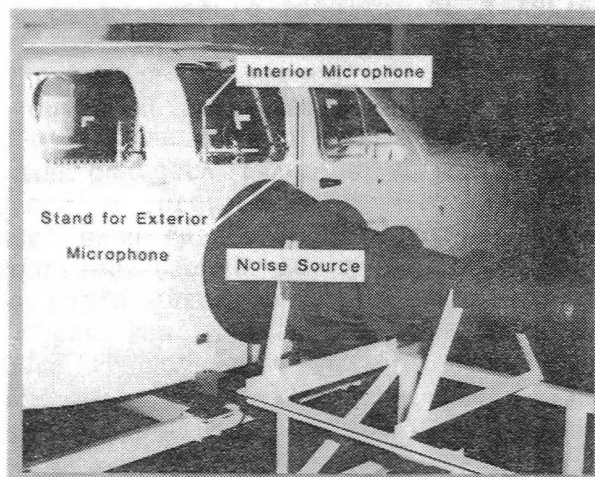
Approach - A general aviation airplane fuselage was placed in a large chamber as shown in the photograph. To reduce reflections, the fuselage was surrounded by fiberglass baffles. Broadband white noise was emitted from an exponential horn attached to a pneumatic air driver positioned at angles at $+45^\circ$, 0° , and -45° with respect to the normal to the fuselage sidewall. Ambient temperature in the test area and cabin were varied within the limits of the HVAC system in the test area. Interior sound pressure levels were measured and recorded at the approximate head positions of the six passengers. Space-averaged results were calculated by energy averaging the six interior sound pressure level data for a particular sound source angle.

Accomplishment Description - A typical narrow band interior noise spectra, as indicated in the upper right figure, displays considerable variation with small changes in frequency. The difference between two such spectra at different temperatures is shown in the lower left figure. The variation in level with temperature (up to ± 10 dB over a narrow frequency range) was found to be predictable based on effects of temperature on the speed of sound and its effect on modal response of the acoustic space. The sound pressure level at any given location as indicated in the lower right figure was also found to vary with variations in angle of incidence of the noise source. At higher frequencies, one-third octave sound pressure levels at the pilot seat differed as much as 10 dB for the different source angles. On the other hand the spacial average across all seats was relatively invariant with source angle. The quantification of these types of effects on cabin noise levels in carefully controlled laboratory tests provides very valuable insight into the variability of in-flight acoustic measurements in aircraft interiors.

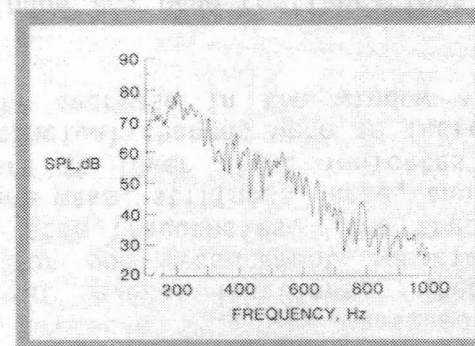
Future Plans - Additional tests are underway with the pictured aircraft fuselage to further the understanding of structureborne noise paths and transmission characteristics.

Figure 22(f).

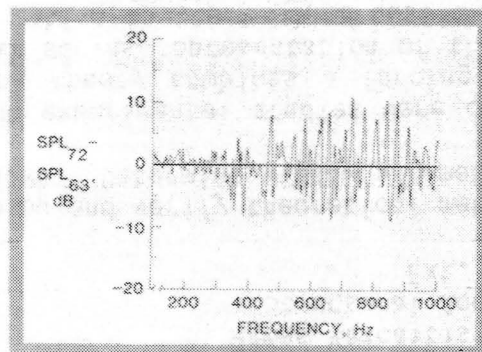
EFFECTS OF TEMPERATURE AND SOUND SOURCE ANGLE ON AIRCRAFT CABIN NOISE



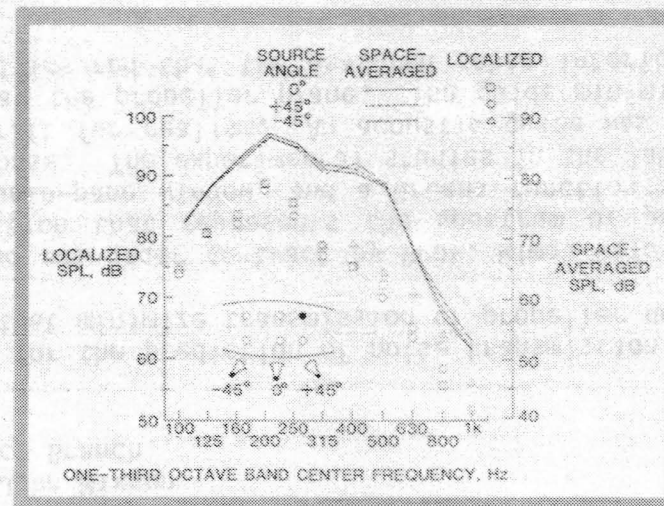
Test Configuration



Typical Cabin Noise



Effect of Temperature



Effects of Source Angle

Figure 22(f).- Concluded.

NOISE TRANSMISSION THROUGH AIRCRAFT WINDOWS

Rimas Vaicaitis and John Mixson
Structural Acoustics Branch
Ext. 3561

Research Objective - Develop and verify theoretical methods for the prediction of noise transmission through double-pane aircraft windows. Determine window parameters that minimize transmission of propeller noise.

Approach - Theoretical and experimental studies were carried out under contract by Prof. Rimas Vaicaitis of Columbia University. The theory combines a forcing function that represents the spectrum of propeller acoustic pressure, a modal series representation of the double-pane window, and a Greens function solution to couple the inner pane motion to the cabin acoustic response. The experimental studies in the laboratory used a fuselage and window of a twin-engine propeller aircraft for realism. An acoustic guide was used to direct the incident sound onto a typical window located near the propeller plane. The guide minimized the sound impinging on other parts of the fuselage exterior and insured that the measured cabin interior noise was transmitted only through the window.

Accomplishment - The figure shows the fuselage used in the tests, however, the wing and engines were removed for these lab studies. The window indicated near the propeller plane has the approximate area, pane thickness, and inter-pane spacing used in many current aircraft in fuselage locations where high noise reduction is needed. For the lab studies the incident sound pressure SPL_o was measured inside the acoustic guide and the cabin interior noise, SPL_i , was measured at several locations. Theoretical and experimental noise reductions shown in the lower left figure for one measurement location, indicate generally good agreement, even though differences are observed at some frequencies. The theory was also used to examine variations of interior noise with variations of pane mass, stiffness, area, and spacing for a simulated propeller and boundary layer noise source. The figure at lower right indicates substantial reductions of interior noise for optimum parameter values. The principal changes were an increase of the outer pane thickness (changing both stiffness and mass), a small decrease in the window area, and an increase in weight of 1.8 pounds per window.

Future Plans - A series of parametric studies for a variety of window and pane configurations mounted a 4 ft. by 5 ft. aircraft sidewall panel will be conducted in the Transmission Loss Apparatus of the Structural Acoustics Branch.

Reference - Vaicaitis, R: Study of Noise Transmission through Double Wall Aircraft Windows. NASA CR 172182, October 1983.

Figure 22(g).

NOISE TRANSMISSION THROUGH AIRCRAFT WINDOWS

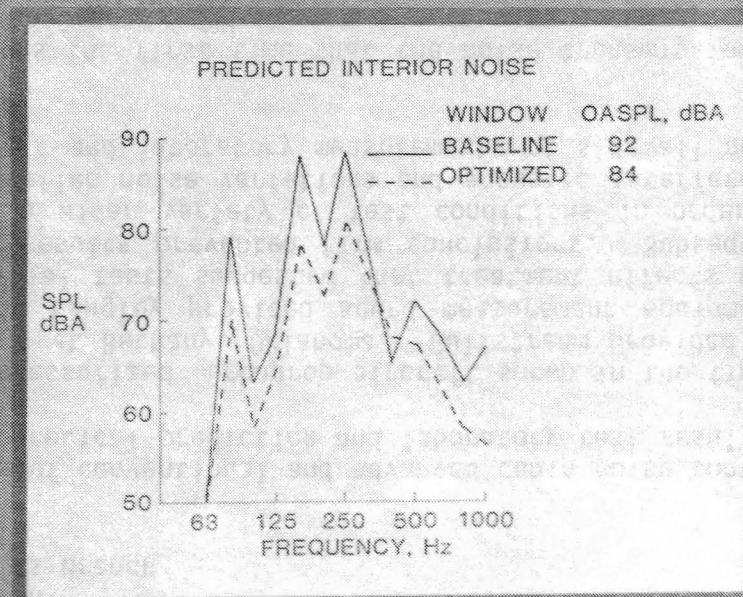
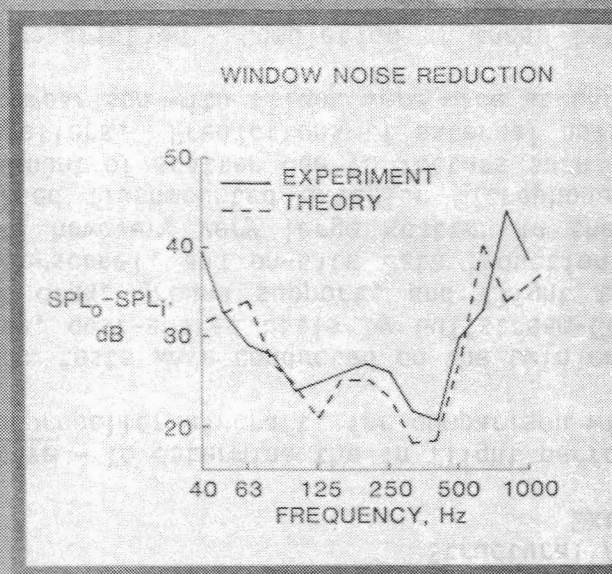
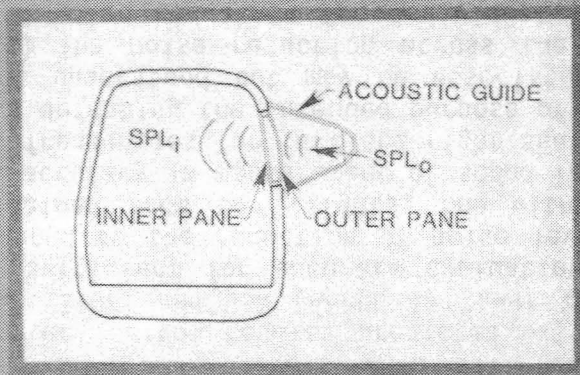


Figure 22(g).-Concluded.

FLIGHT STUDY OF AIRCRAFT SIDEWALL NOISE TRANSMISSION

John S. Mixson
Structural Acoustics Branch
Ext. 3561

Research Objective - To determine the in flight performance of conventional and advanced cabin noise control treatments of a propeller aircraft, for comparison with theoretical prediction and laboratory test results.

Approach - Flight tests were conducted on the twin engine pressurized turboprop aircraft shown in the figure on a cooperative, cost-shared basis by Gulfstream-Commander at Bethany, Oklahoma. Gulfstream provided the aircraft flight crew, ground support, and flight time and Langley provided sound measurement equipment, acoustic test personnel, and on-site data reduction. Initial tests suggested that treatment effects were not as expected; however, very large scatter in the test results prevented firm conclusions. Subsequent tests incorporated flushmounted exterior microphones and a wider variety of test conditions in order to determine the amount of scatter due to factors such as propeller noise variations and acoustic interference of the two propellers. Predictions of external noise levels and laboratory measurements of sidewall noise reduction for comparison with flight were made at Langley.

Accomplishment Description - Completion of these tests marks the first time that the noise transmission of sidewall and treatment of a propeller aircraft has been measured in flight and the results documented for general use. Three results are of particular interest: (a) Measured exterior noise is compared with predictions at the upper right. The propeller noise was found to be repeatable within the limits defined by the colored bands, but the levels were different on the left and right sides of the fuselage and significantly different from results predicted using standard, empirically based methods of SAE (Aerospace Information Report 1407) and BBN (AFFDL TR 76-91 Vol. I). The differences indicate that these prediction methods are not sufficient for accurate evaluation of treatment effects. (b) The insertion loss of the treatment is defined as the reduction of noise level at a cabin position that is obtained by subtracting sound levels obtained from two flights, one with and one without the treatment, and therefore is very sensitive to the accuracy in measurement of sound level. The lower left figure shows that insertion loss is different at low frequencies for left and right seats in the propeller plane and has negative values at many frequencies, thus defeating the intended purpose of noise reduction by the added treatment. The reasons for this are not yet understood but may be associated with modal response of the fuselage cavity at lower frequencies. (c) The noise reduction across the total structure must be known for acoustic treatment design. Measured noise reduction for individual propeller harmonics, shown at lower right for untreated sidewalls and fiberglass wool treated sidewalls, has considerable scatter at some frequencies and is associated with changes in cabin pressure, and aircraft altitude. The fiberglass treatment significantly increases noise reduction above the fourth harmonic, about 300 Hz, as expected based on laboratory tests, and untreated sidewall results show that flight noise reduction is significantly greater than expected from lab measurement of transmission loss. These are significant design considerations because noise in the lower propeller harmonics is the usual cause of passenger discomfort.

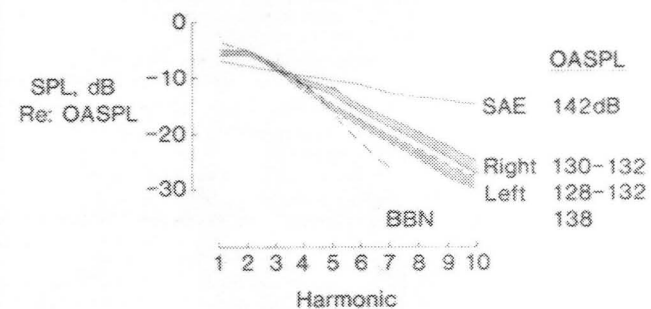
Figure 22(h).

FLIGHT STUDY OF AIRCRAFT SIDEWALL NOISE TRANSMISSION

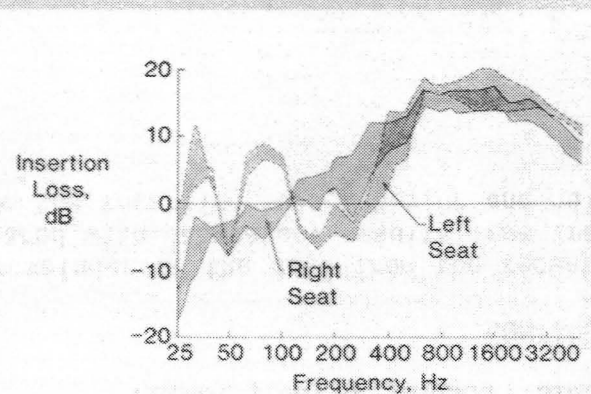
CONTINUED

Future Plans - The remainder of the data from the recent flights is to be reduced and analyzed. The flight results will be compared with laboratory results from transmission loss tests and complete fuselage tests to determine reasons for the insertion loss behavior and noise reduction differences noted above.

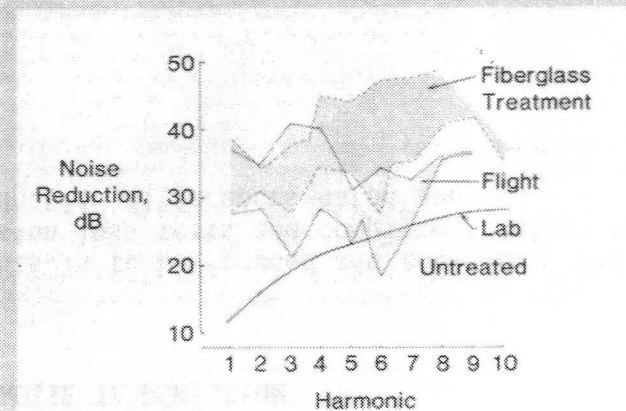
FLIGHT STUDY OF AIRCRAFT SIDEWALL NOISE TRANSMISSION



PROPELLER NOISE ON FUSELAGE



INSERTION LOSS OF SIDEWALL TREATMENT



SIDEWALL NOISE REDUCTION

Figure 22(h).- Concluded.

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VALIDATION OF PROPELLER AIRCRAFT INTERIOR NOISE MODEL

Todd B. Beyer, William H. Mayes, and Edward F. Daniels
Structural Acoustics Branch
Extension 3561

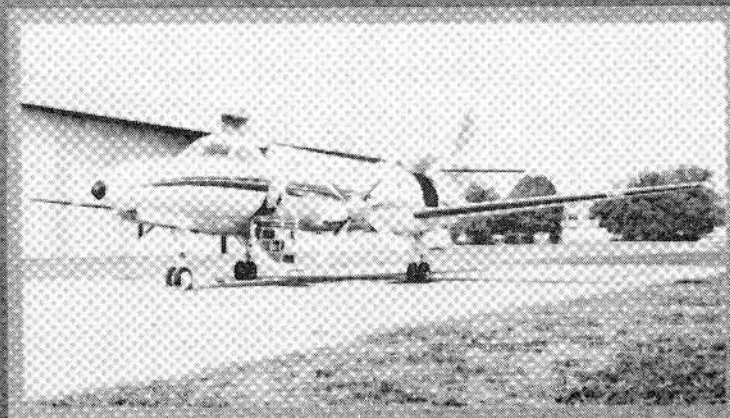
Research Objective - Development and validation of a propeller aircraft interior noise analytical prediction method.

Approach - An analytical Propeller Aircraft Interior Noise Model (PAIN) was developed by BBN under contract and is based on the concept of acoustic power flow. The analysis was initially validated by measurements on a simplified propeller/fuselage model and progressed to models with more realistic structural and interior trim details. The most recent validation was obtained from ground run-up and flight test data for a Merlin IVC aircraft.

Accomplishment Description - Passenger acceptance of propeller aircraft, especially for new aircraft such as the planned fuel-efficient high-speed turboprop aircraft, is highly dependent upon the control of interior noise levels. It is desirable and efficient to predict the levels and to optimize noise reduction treatments early in the aircraft design stage. The model uses measured or predicted propeller pressure loadings or the fuselage as input. The modal characteristics of the fuselage are predicted and radiated acoustic energy is coupled to the interior acoustic space using finite element and statistical energy analysis methods. Typical comparisons of these predictions and full scale flight test data are shown in the figure. The flight measurements are for an executive version of the twin engine commuter Merlin IVC aircraft. This aircraft has a 66 inch diameter cylindrical fuselage and is powered by 1000 SHP turbine engines driving 106 inch diameter propellers with a fuselage tip clearance of 6-3/4 inches. The exterior propeller noise loading is predicted using ANOPP. The good agreement between the predicted and experimental data is considered confirmation of the general validity of the power flow approach.

Future Plans - The Propeller Aircraft Interior Noise (PAIN) computer program is being made available to the United States aircraft industry and research organizations to further validate the technique. Parametric studies are being performed to optimize existing and newly developed noise reduction techniques.

VALIDATION OF PROPELLER AIRCRAFT INTERIOR NOISE MODEL



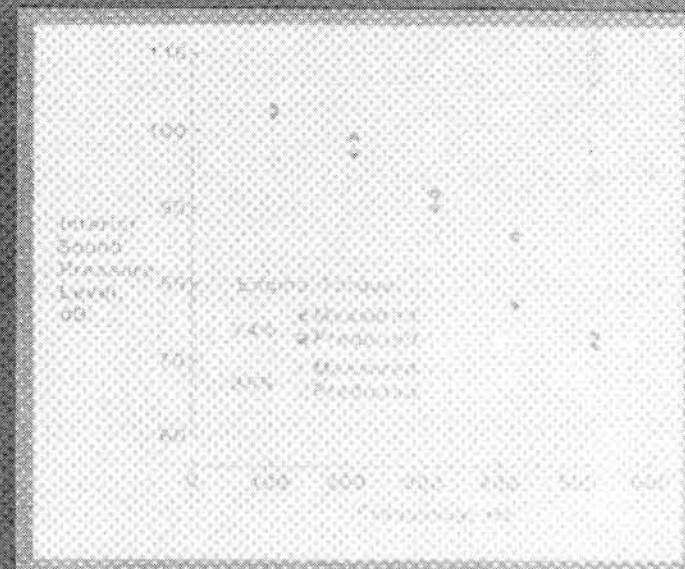
TEST AIRCRAFT

Interior
Acoustic
Space
(ICM & ICA)

Amplitude & Phase
of Propeller Loading
(ANOPP)

Finite-Element
Coupling

MODEL ELEMENTS



IN-FLIGHT VALIDATION

Figure 22(i).- Concluded.

VALIDATION OF HELICOPTER INTERIOR NOISE MODEL

William H. Mayes
Structural Acoustics Branch
Extension 3561

Research Objective - Develop an effective and efficient helicopter interior noise prediction model for use in noise control and design.

Approach - Sikorsky Aircraft, under contract to NASA, has developed an analytical helicopter interior noise model based on the statistical energy analysis (SEA) of the airborne and structureborne (vibrational) energy paths. Paths by which energy is transmitted are a function of the noise/vibration source and its location relative to the cabin. All of the noise radiated into the cabin is ultimately airborne but the energy path and point from which it is radiated must be determined for efficient noise control design.

Accomplishment Description - The main feature of the SEA model are shown in the left inset of the figure. Each acoustic and structural subsystem is modelled using its static and dynamic properties (either measured or predicted). The power flow is calculated for each subsystem and then all subsystems are interconnected to obtain an energy balance for the total system. The model predicts the vibration and noise due to each source/path combination as well as the total interior noise. An example of the predictions by the model are compared with the range of measured noise levels inside an S-76 helicopter in the lower right figure. The comparisons shown are for the four speech interference octave bands and their numerical average (SIL-4). For this helicopter at the low speed cruise condition shown, the main gear box is the dominant contributor to the cabin interior noise for the frequency range of 500 to 4000 Hz. The accelerations measured at the four transmission attachment points were used as input to the SEA model. The excellent agreement shown for the interior noise levels, along with the good agreement obtained between measured and predicted vibration levels of the structural subsystems, supports the validity of the SEA model.

Future Plans - Current efforts are underway to customize noise treatments and vibration isolator design for installation on the S-76 for further validation of the model.

Figure 22(j).

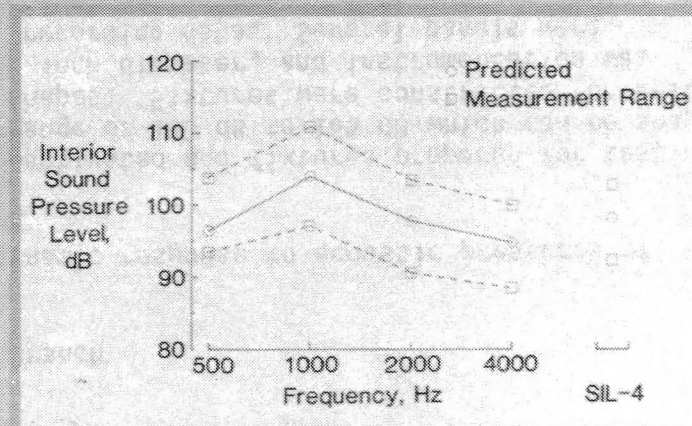
VALIDATION OF HELICOPTER INTERIOR NOISE MODEL



TEST HELICOPTER

- ACOUSTIC/STRUCTURE SUB-SYSTEM PARAMETERS
 - STATIC (GEOMETRY AND MATERIALS)
 - DYNAMIC (MODE DENSITY, DAMPING, COUPLING LOSS FACTOR)
- SUB-SYSTEM POWER FLOW
- ENERGY BALANCE

STATISTICAL ENERGY ANALYSIS MODEL



INFLIGHT VALIDATION

Figure 22(j).-Concluded.

ACOUSTIC RESPONSE AND FATIGUE OF ADVANCED COMPOSITES

John S. Mixson
Structural Acoustics Branch
Ext. 3561

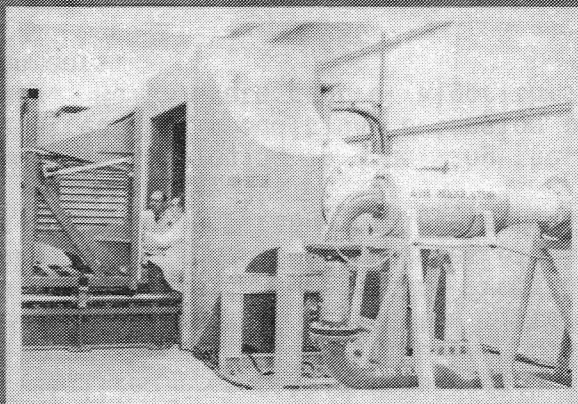
Research Objective - Initiate study of the stress and strain dynamic response to acoustic pressures of graphite-epoxy composite panels.

Approach - The Thermo Acoustic Fatigue Apparatus (TAFA) was re-activated and fixtures prepared for testing composite panels. The facility generates sound levels in the range of 130 dB to 165 dB which can be shaped using electronic input controls to obtain a range of spectrum shapes. Fixtures were constructed for testing rectangular panels of 12 by 15 inches and circular panels of 12 inch diameter, and instrumentation was installed for controlling and shaping the sound inputs and for recording data. Several panels were constructed having various lay ups and two thicknesses. Theoretical analysis was begun for comparison with the test results.

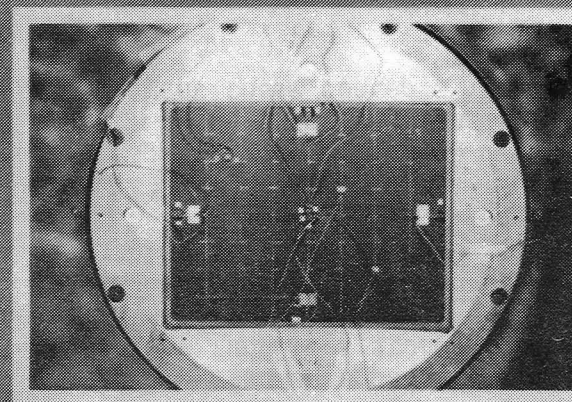
Accomplishment Description - Testing and analysis were initiated in March 1985. Bending and in-plane strains were measured at nine locations on a panel having eight layers oriented with the pattern $[0, \pm 45^\circ, 90^\circ]$ symmetric about the control plane. Sound levels varied from 130 dB to 155 dB and included both broadband spectra and narrowband inputs to frequencies of 50 Hz to 150 Hz. Preliminary tests were done to study the modal response of the panels and the acoustic pressure characteristics of the sound impinging on the panel. Stress analysis was carried out by Prof. Chuh Mei of Old Dominion University emphasizing large amplitude non-linear panel response as affected by non-linear panel damping.

Future Plans - Analysis of the test data is underway. Tests are being set up in the Acoustics lab for testing at lower sound levels and with more controlled sound inputs and temperature. A temporary control room is being set up at TAFA and instrumentation is being acquired for test control and data recording and analysis.

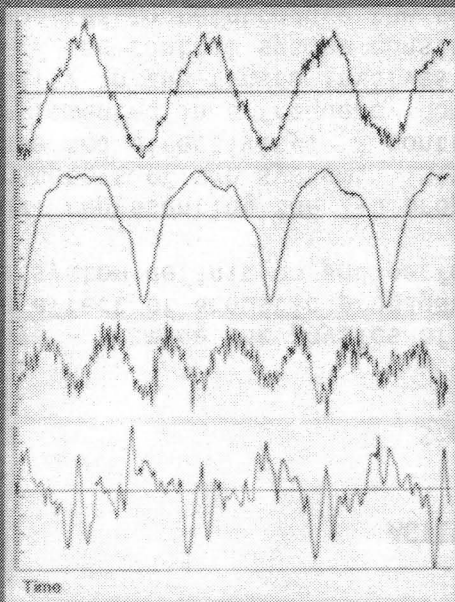
ACOUSTIC RESPONSE AND FATIGUE OF ADVANCED COMPOSITES



Thermo-Acoustic Fatigue Apparatus



12 x 15 inch Panel Installation



Sound Pressure
140 dB at 60 Hz

Bending Strain

Membrane Strain

Acceleration

- Testing Started March 1985
- Five Layups, Graphite-Epoxy, 0.04 & 0.08 in. Thick
- Stress Analysis Underway ODU
- Laminate Properties Measured

Figure 23.- Concluded.

ACTIVE CONTROL OF RANDOM NOISE

Richard J. Silcox
Structural Acoustics Branch
Ext. 3561

Research Objective - Examine the physics of active control of broadband random noise propagating in 1-D waveguides. The effect of acoustic propagation, transduction, control parameters, and algorithm is examined as it relates to system definition and performance.

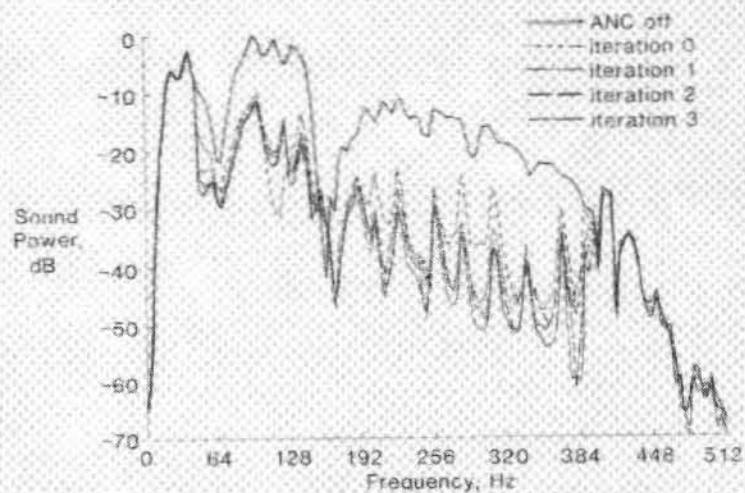
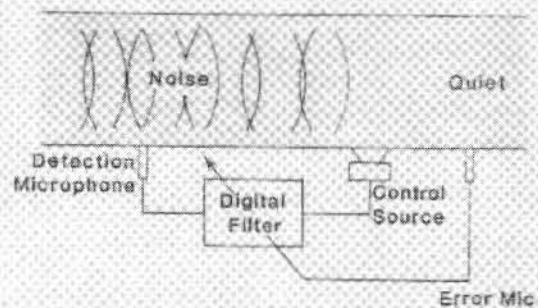
Approach - A model representing the 1-D propagation of broadband sound in waveguides was derived in terms of the physical parameters of the system. This model includes the effect of termination conditions, transducer frequency response and directivity. A control algorithm is defined in terms of measurable system transfer functions and implemented in a frequency domain approach. Experimentally, the system shown schematically and photographically in the figure involves an acoustic space in which it is desired to maintain a measure of noise control. The control system consists of a detection microphone, an arbitrary digital filter and a control source/speaker to reintroduce the sound in the waveguide. The control algorithm measures the system performance via the error microphone and attempts to maintain a minimum output from this transducer by manipulating the filter characteristics.

Accomplishment Description - By utilizing an adaptive approach to implementing the control algorithm, the system may be initialized from stored data and then made to adapt for maximized performance under different or even changing conditions. For the inset of noise suppression, system transfer functions stored from previous measurements are used to define the filter implemented for iteration 0. This provides the initial increment and bulk of the noise suppression from the control off case. Subsequent iterations increase the effectiveness through three additional cycles of the control algorithm converging to 15 to 30 dB of suppression over the frequency range of interest.

Future Plans - Work is continuing in modelling the details of the controlled spectra and including finite impedance source effects. In addition, extension of these concepts to control noise in multidimensional spaces is underway. Multivariate control algorithms must be developed to implement these concepts in practical environments.

Figure 24(a).

ACTIVE CONTROL OF RANDOM NOISE



Noise Suppression

Figure 24(a).- Concluded.

CONTROL OF INTERIOR NOISE BY PROPELLER SYNCHROPHASING

Richard J. Silcox
Structural Acoustics Branch
Ext. 3561

Research Objective - Investigate analytically and experimentally the structural and acoustical characteristics of aircraft fuselages that determine the effectiveness of multi-engine propeller synchrophasing for interior noise control.

Approach - An aircraft fuselage as shown in the figure is modelled as an infinite cylindrical shell with typical materials and properties. Propeller noise sources are represented by an arrangement of simple point sources that reproduce measured fuselage pressure data. By varying the phase between the sources, the effects on the cylinder vibration and interior acoustic field can be determined for a variety of structural elements such as cylinder properties, a floor or wall stiffeners. An experimental program is underway to provide verification data from a structurally simple test case and as a screening tool to give insight as to which structural and acoustic components are important.

Accomplishment Description - This research has revealed the manner in which the low frequency sound transmission into the fuselage model is governed by modal cylinder vibration rather than localized transmission. This motion is most dominant in the source (propeller) plane as is the interior sound level. Further, in many cases the sound transmission has been shown to be dominated by just a few modes, although the modal density is quite high. This implies that effective noise control may be effected by controlling only those structural modes that couple well the interior and exterior sound fields. Experimental verification is shown on the figure where measurements of the interior sound pressure level at a single point are superimposed on the theoretical results for a full range of synchrophase angle. Here, the SPL reduction of 40 dB at a synchrophase angle 180 degrees is along the vertical axis, an axis of symmetry between the sources. At other locations within the model cylinder, although suppressions were not as dramatic, there is significant global reduction (>10 dB) for a single optimum synchrophase angle.

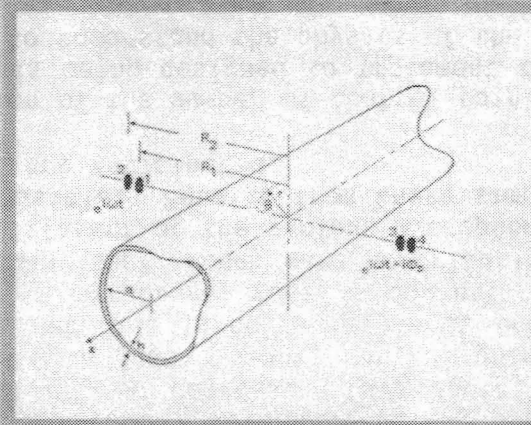
Future Plans - The effect of the floor structure, source location and characteristics, and interior damping are currently under investigation. Additional parametric studies using the present and ongoing modifications are anticipated. Also, investigations utilizing active noise and vibration control concepts are underway.

This work is being performed under Grant NAG1-390 by Dr. C. R. Fuller of Virginia Polytechnic Institute and State University.

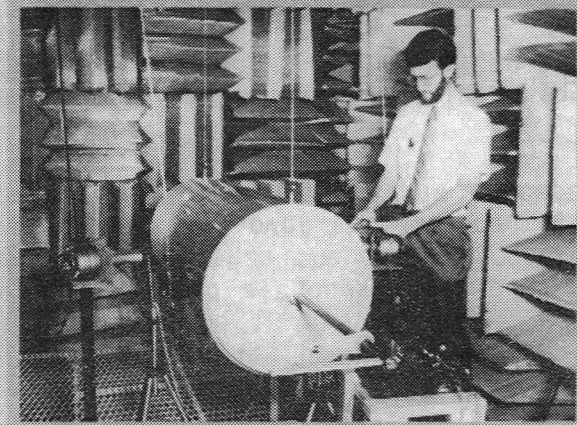
Figure 24(b).

CONTROL OF INTERIOR NOISE BY PROPELLER SYNCHROPHASING

Model Geometry



Validation



Results

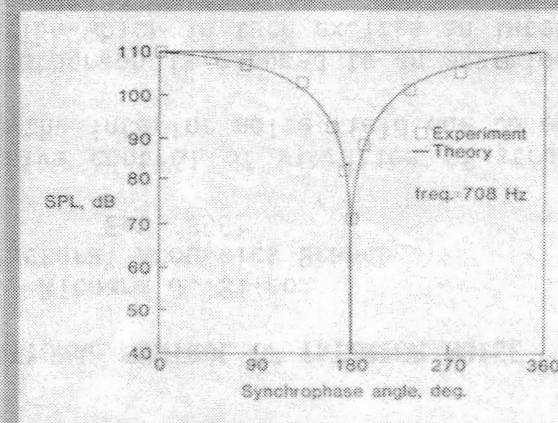


Figure 24(b).- Concluded.

ACTIVE VIBRATIONAL CONTROL OF INTERIOR NOISE

Richard J. Silcox
Structural Acoustics Branch
Ext. 3561

Research Objective - Examine the use of active control of vibration of structural elements of a cylinder representing an aircraft fuselage to control the interior noise field due to exterior sources.

Approach - A finite cylinder shown in the photograph is exposed to an exterior tonal noise source. In this manner the cylinder shell is forced into motion which in turn excites an interior acoustic field. A shaker rigidly attached to the cylinder wall and operating against only its own inertia is driven with a tone of the same frequency and the input adjusted in amplitude and phase in such a manner as to minimize the interior sound pressure level at a point.

Accomplishment Description - In the configuration inset, the microphone locations relative to the point of acoustic excitation are shown. At each location, a minimum attenuation of 10 dB is attained at a common controller phase angle of 180 degrees. This indicates that noise suppression over an extended spatial domain may be attained with just a single control point. At controller phase angles bounding zero degrees, the results indicate a net rise in noise levels as the two noise sources combine in phase. These results imply that only a single structural mode is dominating the interior noise field although many modes exist within the shell. If many shell modes were contributing to the interior noise, then the optimum controller phase angle would be different at the various microphone locations and suppression over the extended spatial domain would not be possible. Results from these simple experiments indicate promise for this concept and further investigations are anticipated.

Future Plans - Expansion of the number of control points to a maximum of four is planned and a least squares convergence algorithm is being designed to implement the controller function. Analytical modelling is also underway in an effort to understand the physics of the controls problem.

This work is being performed under a grant to VPI & Su by Dr. C. R. Fuller.

Figure 24(c).

ACTIVE VIBRATIONAL CONTROL OF INTERIOR NOISE

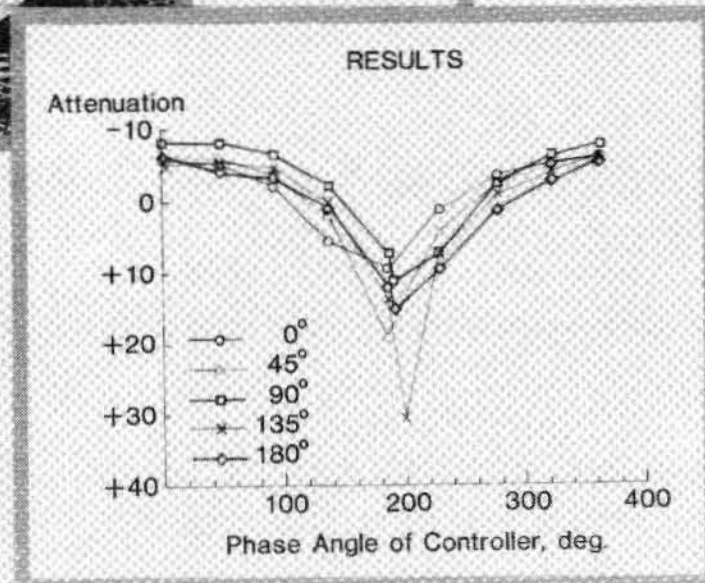
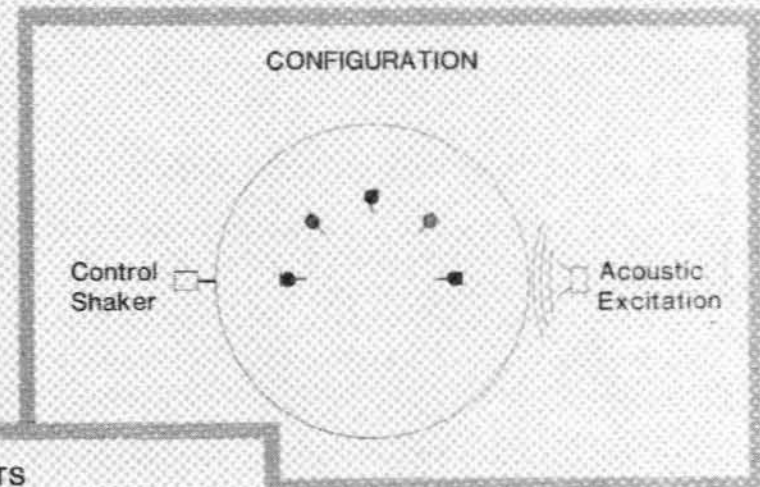
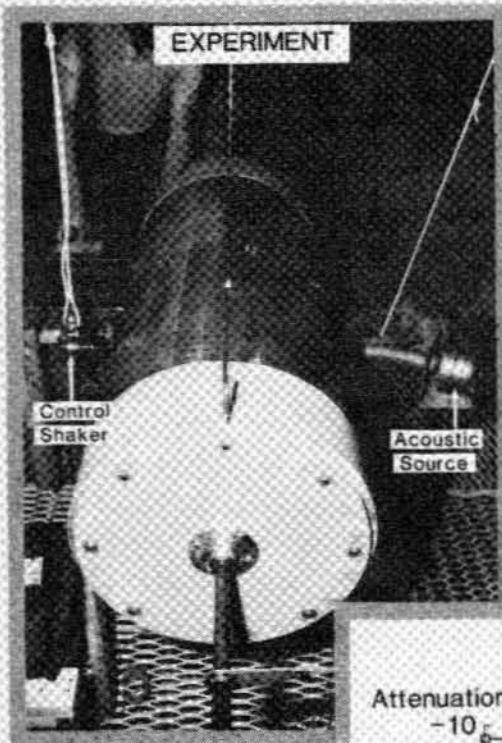


Figure 24(c).- Concluded.

ACTIVE INTERIOR NOISE CONTROL MODELLING

Harold C. Lester
Structural Acoustics Branch
Ext. 3561

Research Objective - Exploratory evaluation of basic active noise control concepts as applied to simple aircraft fuselage models for propeller noise sources.

Approach - As shown, the fuselage is modeled as a thin, flexible cylinder. The primary interior acoustic field is produced by two external dipole pairs simulating twin propellers. This simple model is sufficiently accurate for approximating the acoustical-structural interactions occurring at typical blade passage frequencies (100-500 Hz) and the lower harmonics. A secondary (control) field is produced by a distribution of interior monopole acoustic sources. The amplitude and phase of the control sources are determined so that the combined interior noise field (primary plus secondary) is less than the original primary field.

Accomplishment Description - The top middle inset is a map of the sound pressure levels of the primary acoustic field when the external dipoles (propellers) are phased for maximum (worst case) interior noise. The peak SPL has been arbitrarily set to 100 dB (white). (Relative SPL levels were indicated by the color bar, in the original figures.) The effects of active noise control (ANC), shown in the top right color inset, reduce the maximum interior noise levels by about 15-20 dB. In order to maximize the effectiveness of the secondary field the control sources were located in the lighter shaded positions (top left inset).

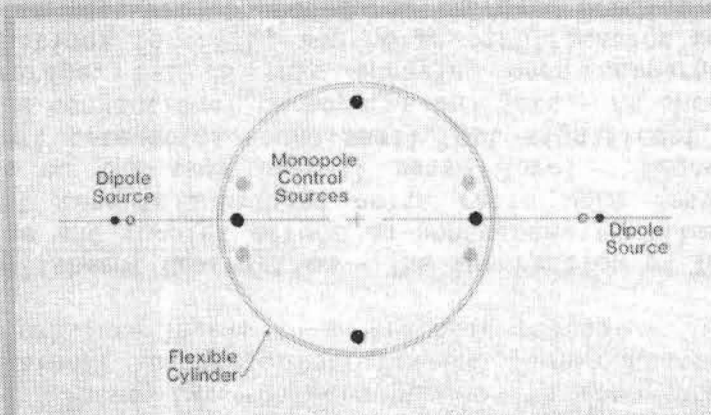
If the external sources are phased for minimum noise, the interior (primary) SPL color map is as shown in the bottom left inset. Active noise control (ANC) applied to this situation produces the interior noise field color mapped in the bottom right inset. In combination with optimum source phasing, this ANC model produces even greater noise reductions of 20-30 dB over an even larger region of the fuselage cross-section. For this case, effective control is obtained with the monopole acoustic sources located at the darker shaded positions (top left inset).

Future Plans

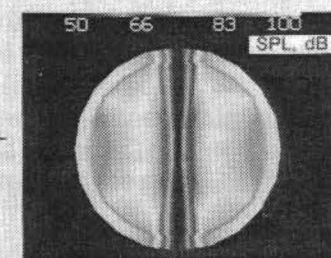
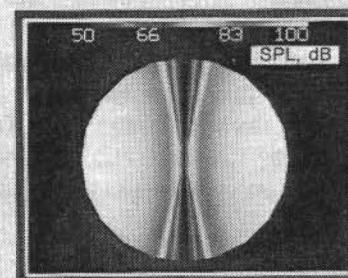
A comprehensive research study is underway to evaluate this ANC model and, in particular, a complementary experiment is being developed to provide measured data for concept validation.

Figure 24(d).

ACTIVE INTERIOR NOISE CONTROL MODELING

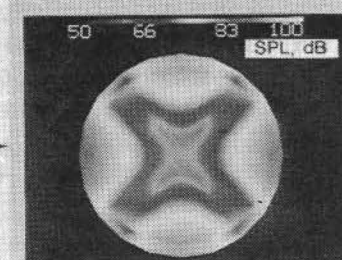
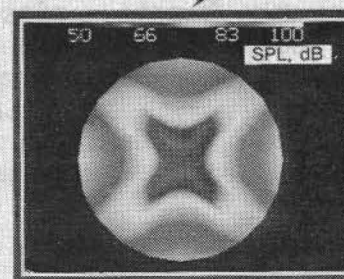


OUT-OF-PHASE DIPOLES



ANC

Synchrophasing



ANC

IN-PHASE DIPOLES

Figure 24(d).- Concluded.

QUANTIFICATION OF ADVANCED TURBOPROP AIRCRAFT FLYOVER NOISE

David A. McCurdy
Structural Acoustics Branch
Ext. 3561

Research Objective - This program was conducted to compare the annoyance response to advanced turboprop (ATP) aircraft flyover noise with the response to flyover noise of conventional turboprop and jet aircraft. ATP noise is unique in that the propeller harmonic tone components occur at frequencies higher than those of conventional propeller aircraft but lower than fan tones of conventional jet aircraft. In addition to comparing the three categories of aircraft, the annoyance effects of the propeller harmonic tone characteristics such as blade passage frequency and tone-to-broadband noise ratio were examined. The third objective was to determine the annoyance prediction ability of EPNL, the aircraft noise certification metric for ATP.

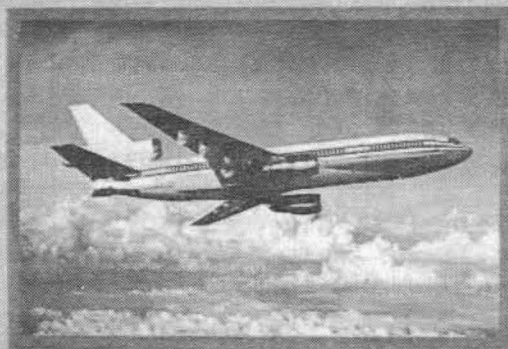
Approach - A computer synthesis system was used to generate 18 realistic, time varying simulations of ATP aircraft takeoff noise in which the harmonic content was systematically varied to represent combinations of six fundamental frequencies ranging from 67.5 Hz to 292.5 Hz and three tone-to-broadband noise ratios of 0, 15, and 30 dB. The range of fundamental frequencies covered both conventional and advanced turboprop aircraft. The simulations assumed a single propeller, wing-mounted, tractor configuration using the SR-3 blade. Thirty-two subjects judged the annoyance of these ATP simulations as well as recordings of five conventional turboprop takeoffs and five conventional jet takeoffs, all presented at three representative sound pressure levels in an anechoic chamber.

Accomplishment Description - The interaction of fundamental frequency with tone-to-broadband noise ratio had a large and complex effect on annoyance, as illustrated in the lower left figure. The conditions with the highest tone-to-broadband noise ratio were less annoying than those with lower tone-to-broadband noise ratios at the same overall noise level. Regression analyses of the annoyance responses for the three aircraft categories found small, but significant, differences in annoyance between the advanced turboprops and the conventional turboprops and jets. As shown in the lower right figure, the advanced turboprops were, on average, 1-2 dB less annoying when compared on an equal EPNL basis. Other results, which have implications for EPNL, the noise certification metric, indicated that the addition of duration corrections to noise measurement procedures improved prediction ability and that corrections for tonal content should be limited to tones above 500 Hz.

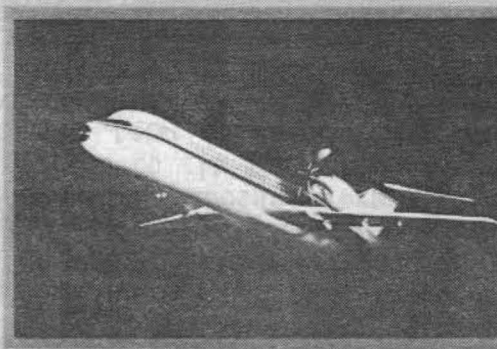
Future Plans - Additional tests will study annoyance response to counter-rotating, aft-mounted, pusher configuration now expected to be used on first generation commercial transport aircraft.

Figure 25(a).

QUANTIFICATION OF ADVANCED TURBOPROP AIRCRAFT FLYOVER NOISE



Conventional Jets



Advanced Turboprops



Conventional Turboprops

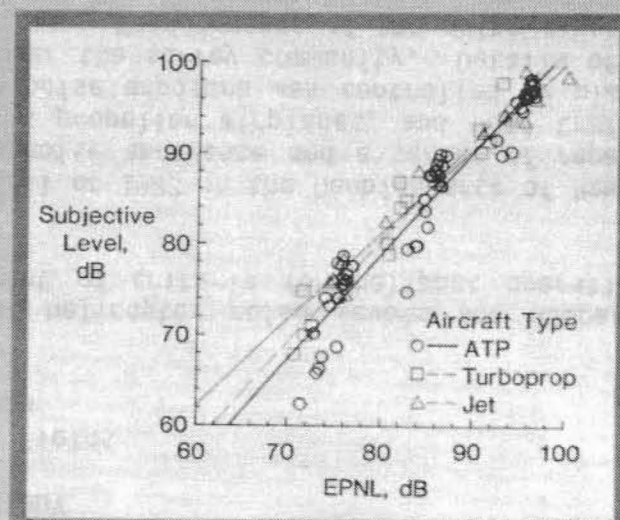
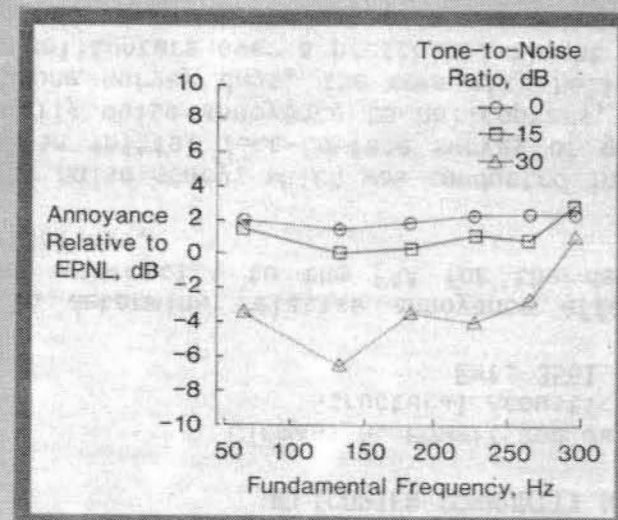


Figure 25(a).- Concluded.

HELICOPTER COMMUNITY NOISE STUDY

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Ext. 3561

Research Objective - To determine relative annoyance effects of helicopter noise levels and number of overflights to provide information to the FAA for the development of criteria for heliport operations, siting and land-use guidelines.

Approach - The community noise study, which was conducted in the Fall of 1983 in the Denbigh area of Newport News, VA, consisted of an initial face-to-face survey of general noise annoyance and a series of repeated telephone surveys of daily noise annoyance to helicopters, jet and propeller airplanes, and road traffic. On 17 of the 23 telephone survey days, the community helicopter noise exposure was controlled by planned flights of Fort Eustis helicopters over a prescribed flight path over the survey community. Details of the exposure conditions and surveys are indicated in the attached figure. Measurements of the noise exposures were made on each flight day at three locations in the community and the telephone surveys were conducted during the early evening following the exposures. In both the face-to-face and telephone surveys annoyance to each noise source was scored on a "0" (not annoying at all) to "10" (extremely annoying) scale.

Accomplishment Description - Because of the typically low number of daily operations there is uncertainty in the applicability to heliport community noise exposure of the energy averaging noise metrics which are used to quantify community noise exposure around conventional airports. The present study provides data at low daily exposure rates to determine the effects of number of flyovers relative to the effects of noise level and to assess the applicability of energy averaging noise metrics. The lower left figure presents the average annoyance score, normalized to the mean sound exposure level, (SEL) as related to the number of flyovers. A logarithmic function of number was found to fit the data better than a linear function or other functions. The coefficient for the logarithmic term (8.1) was not significantly different from the theoretical value of 10 for a pure energy average effect. The lower right figure indicates the relationship of annoyance and the energy average metric, LEQ, which is currently used to assess conventional airport community noise exposure. A consistent trend for increasing annoyance with increasing LEQ is indicated for LEQ above 45 dB, thus indicating the applicability of this energy averaging noise metric.

Future Plans - All data analysis is complete and a presentation of results to the FAA has been made. A final report has been drafted for submittal to the FAA to complete contractual obligations. A laboratory study to determine the effect of different house attenuation characteristics on helicopter annoyance is being planned.

Figure 25(b).

HELICOPTER COMMUNITY NOISE STUDY

NOISE EXPOSURE CONDITIONS

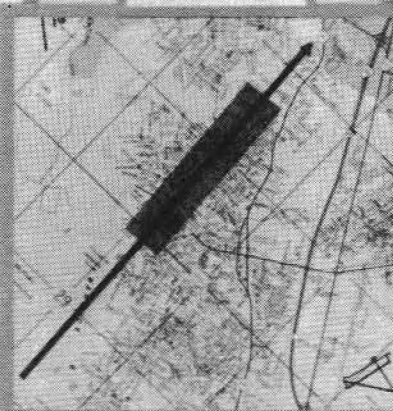
UH-1H

- 1500 FT. ALTITUDE
-75 dB[A]
- 1,2,4,8,15,20,32
FLIGHTS/DAY
- 500 FT. ALTITUDE
-85 dB[A]
- 2.8
FLIGHTS/DAY

UH-60A

- 1500 FT. ALTITUDE
-75 dB[A]
- 2.8
FLIGHTS/DAY
- 500 FT. ALTITUDE
-85 dB[A]
- 2.8
FLIGHTS/DAY

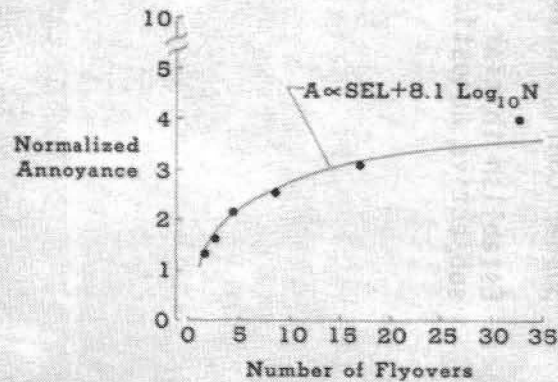
TEST AREA



COMMUNITY SURVEY INFORMATION

- 861 RESIDENTS IN TEST AREA
- 338 FACE TO FACE SURVEYS
- 285 TELEPHONE SURVEYS PER EXPOSURE
- 328 FINAL TELEPHONE SURVEYS
- HELICOPTER, JET AIRPLANE, PROPELLER
AIRPLANE, CAR, TRUCK, MOTORCYCLE
ANNOYANCE QUESTIONS

EFFECT OF NUMBER



EFFECT OF TOTAL EXPOSURE

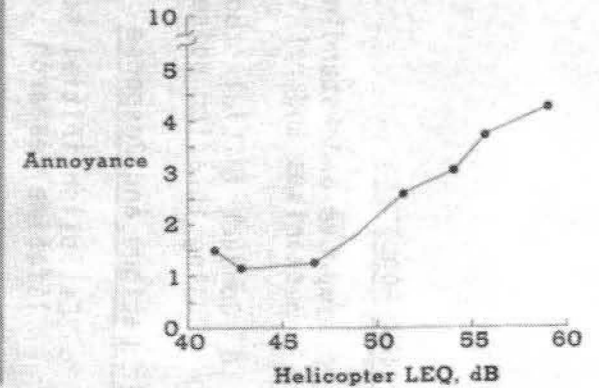


Figure 25(b).- Concluded.

Structural Acoustics

FY 86 PLANS

Interior Acoustics

- o Improve understanding of structureborne noise transmission mechanisms and paths
- o Conduct initial study of source, structure and treatment effects using interior noise prediction model and composite cylinder

Sonic Fatigue and Response

- o Establish initial testing capability for acoustic response and lifetime research
- o Complete initial studies of strain response of composite panels

Active Noise Control

- o Design and implement experiments and simulation capability for evaluation of active noise control concepts
- o Evaluate optimum configuration of control sources for active noise suppression

Subjective Acoustics

- o Quantify subjective response to noise from counter-rotating and pusher configurations of advanced turboprop aircraft
- o Establish initial testing capability for space station subjective acoustic studies

Figure 26.

STRUCTURAL ACOUSTICS BRANCH FY 86 PLANS: NARRATIVE

Interior Noise

The main emphases in interior noise research for FY 86 will be in the areas of structureborne noise and noise transmission through composite structures. The area of structureborne noise is of particular interest for some proposed configurations of Advanced Turboprop Aircraft (ATP). A number of contract and grant activities are underway to provide basic information of the mechanisms and paths of structureborne vibrational energy which can radiate into aircraft and spacecraft interiors. In addition, an in-house program has been initiated to study power flow through structural paths using advanced multichannel computer aided test equipment. A parametric study is underway which will investigate the effects of different noise sources and locations and different structural configurations and acoustic treatments on noise transmission into fuselage sections using the Propeller Aircraft Interior Noise model. Results of this study will be compared with experimental data of noise transmission through the 5.5 ft. diameter filament-wound stiffened composite fuselage model described in one of the recent accomplishments. This will provide further verification of the prediction model and determine the sensitivity of aircraft interior noise to details of the noise source and aircraft design.

Sonic Fatigue and Response

The major activity in the sonic fatigue and structural response area will be to establish acoustic response and life time testing capability in the Thermal Acoustic Fatigue Apparatus (TAFA). Measurements and predictions of thermal response of advanced thermal protection system (TPS) panels to intense acoustic loads is planned, however, the high temperature capabilities of the facility need improvements to fully meet requirements to test candidate TPS panels for hypersonic vehicles such the proposed Shuttle II and Aerospace plane. In addition, experimental and analytical studies are underway to determine strain response of advanced composite panels to acoustic loads in geometrically linear and non-linear regions.

Active Noise Control

The use of active noise control in enclosed 3-dimensional spaces has recently become very attractive because of the potential and need for large noise reduction with low weight penalty and because of advances in high speed computational hardware. Advanced Turboprop and Space Station interior noise are just two potential application areas of high interest. The FY 86 in-house research of the Structural Acoustics Branch in this area will concentrate on

Figure 27.

STRUCTURAL ACOUSTICS BRANCH

FY 86 PLANS: NARRATIVE Continued

the development of an experimental apparatus with simulation capabilities for evaluating active noise control concepts and the completion of an analytical and experimental study to determine optimum configurations of control sources used to actively suppress noise in fuselage like structures. In addition, continuation of grant studies in optimizing propeller synchrophasing and active vibrational control of aircraft interior noise is planned.

Subjective Acoustics

The emphases of the subjective acoustics program will include both ATP community noise annoyance and Space Station interior noise. Studies to determine subjective response for counter-rotating and pusher configurations of ATP are planned. The distinguishing noise characteristics for both of these configurations will be higher levels of the higher frequency harmonics due to propeller or pylon wake interactions. For the counter-rotating configurations, there will also be a more complex tonal structure of the noise due to the proposed use of unequal numbers of blades on the fore and aft propellers. The Structural Acoustics Branch has currently under construction an acoustic simulation apparatus for Space Station interior noise research. This apparatus will become operational during the FY 86 fiscal year. Some initial studies of noise level produced by representative Space Station interior noise sources and resulting speech intelligibility are planned for validation of a prediction model being developed under contract.

Figure 27.- Concluded.

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